SUSTAINABILITY ASSESSMENT OF VEGETABLE CULTIVATION SYSTEMS IN THE RED RIVER DELTA, VIETNAM

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ABSTRACT

This study is empirical research by applying different sustainability assessment approaches to evaluate and to compare the sustainability index of the existing vegetable cultivation systems in the Red River Delta - the largest vegetable production land area of Vietnam in terms of environment, economic and social dimensions. In addition, this study also incorporated farmers' perceptions as well as their preferences into the weight of criteria by using Analytic Hierarchy Process (AHP) in multi-criteria evaluation method, and rules formed in fuzzy evaluation method. The results from the sustainability assessment for the vegetable cultivation systems show that in the rural area, the sustainability are acceptable whereas in the peri-urban area are only conditionally acceptable, and in the urban area are not sustainable. The results from this study indicate that, to achieve sustainable vegetable cultivation systems in the Red River Delta in Vietnam, the farmers need improved internal controls and tracing systems as well as strict social control in order to implement good agricultural practices guidelines. This study result also shows that the sustainability assessment by fuzzy evaluation approach appears to be well suited to provide quantitative answers pertaining to sustainability that can help policy maker in choosing the tool for sustainability assessment in the future.

Keywords: Vegetable cultivation systems, sustainability assessment, multi-criteria evaluation, fuzzy evaluation, Red River Delta, Vietnam.

ZUSAMMENFASSUNG

Zur Einschätzungen und Bewertung der Nachhaltigkeit der gegenwärtigen Gemüseproduktion im Roten-Fluss-Delta, Vietnam, erfolgten empirische Untersuchungen zur Ermittlung und Bewertung eines Nachhaltigkeitsindex unter Nutzung verschiedener Lösungsansätze.
Die Analysen und Einschätzungen wurden aus ökologischer ökonomischer und sozialer Sicht vorgenommen. Die erfassten Daten wurden unter Nutzung von zwei Methoden ausgewertet, der Mehr-Kriterien-Bewertungsmethode Analytic Hierarchy Process (AHP) und der Fuzzy Bewertungsmethode. In Workshops wurden mit den Farmern Präferenzen als Element der AHP, zu den Kriterien die Ausdruck der Nachhaltigkeit sind, erarbeitet. Es wurde herausgearbeitet, dass im ländlichen Raum, die Gemüseproduktion nachhaltig ist, im Peri-urbanen Raum wurde eine geringe Nachhaltigkeit ermittelt und im urbanen Raum keine Nachhaltigkeit. Im Ergebnis der Forschungsarbeit wurde herausgearbeitet, dass für einen nachhaltigen Gemüse-Anbau im Roten-Fluss-Delta, die Farmer ihr Kontrollsystem und System der Nachverfolgbarkeit verbessern müssen. Gleichermaßen ist es erforderlich die sozialen Bedingungen so zu gestalten, das die Prinzipien der, Guten Landwirtschaftlichen Praxis‘ greifen. Im Rahmen der Forschungsarbeit konnte gleichfalls eine Bewertung der Nachhaltigkeit unter Nutzung der Fuzzy Methode erfolgreich eingesetzt werden. Diese Ergebnisse sind geeignet, sowohl den Farmern, als auch den politischen Entscheidungsträgern, die geeigneten Werkzeuge für die Entwicklung einer nachhaltigen Gemüse Kultivierung in der Zukunft zu geben.

Keywords: Gemüse, Kultivierungssysteme, Einschätzung der Nachhaltigkeit, Mehrfaktorenbewertung, Fuzzy Bewertung, Roter-Fluss-Delta, Vietnam.

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LIST OF ABBREVIATIONS, SYMBOLS AND EQUIVALENTS

%	Percent
ha	Ha
sao	1 sao = 360 m^2
m^2	square meter
kg	Kilogram
g	Gram
1 USD	19,700 VND (June 2010)
AAE	Access to agricultural extension
AC	Access to credit
AHP	Analytic hierarchy process
CLC	Cultivation of legume crops
EMC	Efficient of market channel
ECOLsus	Ecological sustainability
ECONsus	Economic sustainability
EPL	Employment
FAO	Food and agriculture organization of the United Nations
FIS	Fuzzy inference systems
FR	Financial return
Gaussmf	Gaussian curve built-in membership function
GM	Gross margin
GR	Gross revenue
HH	Human health
IPM	Integrated pest management
ISS	Input self-sufficiency
IYT	Index of yield trend
MADM	Multiattribute decision making
max (s)	Maximum values
MF	Membership Function
min (s)	Minimum values
MODM	multi-objective decision making
I(v)	Normalized value
Osus	Overall sustainability
SOCsus	Social sustainability

T (v)	Target values,
Trapmf	Trapezoidal-shaped built-in membership function
TVC	Total variable costs
UCF	Use of chemical fertilizer
UOF	Use of organic fertilizer
UCC	Management of pests and diseases (use of chemical control)
VND	Vietnamese Dong

1. INTRODUCTION

1.1. Background information

Humanity is facing numbers of challenges such as: population growth, increasing pollution, decline of readily available fossil fuels, decline of freshwater supply, challenges of climate change, soil erosion, biodiversity loss, and social inequality. It puts pressures on us to find how and what is the way we have to organize our agro-food systems for sustainable development.

Sustainability is a prominent concept at the present time. In developing countries, the right attention and attitude to address the future challenge in agricultural production is essential to contribute to sustainable development. To increase productivity in agriculture and horticulture, often higher intensification and increasing amount of fertilizers and pesticides were used by the farmers in order to increase the yield. However, chemical fertilizer, pesticides have direct and indirect negative health effects for the actors directly or indirectly involved in the food supply chain.

Among agro-chemicals, the inorganic fertilizers were popularly used and reached the level of three million tons per year where two million tons are imported. Among the chemical fertilizers, nitrogen was introduced into Vietnam earlier than phosphorous and potassium because of its yield effect. The government has also promoted the use of nitrogen by price incentives. Due to this, there is a belief that farmers over-use nitrogen. Many farmers tend to use urea heavily; knowledge of the importance of potassium and phosphorus may not be enough. At present, extension workers and scientists advise farmers to be aware of balanced fertilizer application.

Fertilizer use in Vietnam increased from about 172,000 tons per year (in nutrient terms) in 1980-1981 to 428,000 tons per year in 1984-1986 to about 500,000 tons per year in 1989-1990. However, average fertilizer consumption per ha is not high by East-Asian standards and by the extent of irrigation in the country (DUNG *et al.* 1997).

In 2010, Vietnam fertilizer consumption grew 6.3% y-o-y (fertilizer consumption in 2009 was 8.3mT) (Figure 1.1), nearly double the volume used five years ago, while the land use for cultivation has been planned to increase only 6% within the next five years (according to the Ministry of Agriculture and Rural Development) (MEKONG SECURITIES 2011).

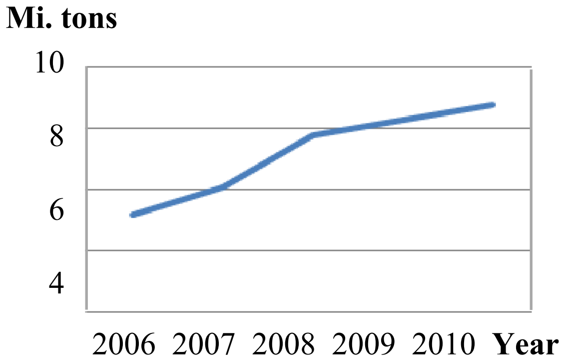

Figure 1.1. Vietnam fertilizer consumption in Vietnam 2006 - 2010
(Source: MEKONG SECURITIES 2011)

According to DUNG *et al.* 1997 environmental issues relating to farming and farming practices have come to the fore in recent years and some of the controversies concern fertilizer use. It is a misconception that the more fertilizer is applied, the more profit can be made. At all times, one should aim for the optimum balance between applied nutrients, and those removed from the harvest. This will help to prevent leaching of excessive nutrients in the environment. Apart from that, time of the year when fertilizers are applied should also be a concern because it has an influence on leaching. The environmental effects due to fertilizer use can be listed as follows (DUNG *et al.* 1997):

1. Nitrogen (N) and Phosphorus (P): Nitrogen and Phosphorus in liquid effluents can contribute to eutrophication in water with a risk of oxygen depletion.
2. Ammonia (NH_3): Ammonia gas can cause haze and contribute to the acidification of soils.
3. Nitrogen oxides (NO_x): Nitrogen oxides can contribute to regional acid precipitation and locally reduced air quality.
4. Sulphur dioxide (SO_2): Sulphur dioxide reacts with other gases and contributes to haze formation and also to regional acid precipitation.
5. Dust: Dust can be a local nuisance and contribute to visible haze.
6. Fluoride (F): In high concentrations, Fluoride is dangerous to plants and animals.

Although these effects are not perceptible to the eye, they can accumulate through time and will lead to a serious degradation of the soil and the environment in general.

In 1990, 94.5 kg NPK was used for one cultivated ha on the average in the world. The intensification in agriculture has made the nitrate level in the soil increase. In 1956, the world nitrogen fertilizer production was only 3.5 million tons (in nutrient term) but in 1975 this increased to 40 million tons (DUNG *et al.* 1997).

When there is surplus nitrogen in the soil, this will be converted to ammonia or nitrate through biochemical processes. In other words, the nitrate content will increase in soil and water resulting in pollution. Nitrate then will be absorbed in the vegetables and cereals leading to excess over the standard nitrate content in food. The standard nitrate in food and drinking water for adult is 300 mg per day and for children is 3 mg per day. In developed countries, cultivated areas were seriously polluted due to farming intensification. Netherland is a typical example, vegetable of this country, especially in winter, can contain 4,000mg nitrate/kg. It was calculated that each person here put into his/her or her stomach 1,100mg nitrate through food and 100 mg nitrate through drinks per day, 4-time exceeding the standard level. This is more serious in case of children (Environment Weekly, No. 10/96 cited by DUNG *et al.* 1997).

In Vietnam, the use of nitrogen fertilizer has increased remarkably due to the intensification of agriculture. However, up until now, there has been no official research on the effects of overuse of nitrogen fertilizer to environment and farmers' health, as well as detection of nitrate content in soil, food, and water is still very limited (DUNG *et al.* 1997).

The use of too much urea that leads to unbalanced fertilizer use is in the long- run not sustainable, too much nitrogen also enhances plant growth that makes it attractive to some insect pests.

Farmers in Vietnam started to use pesticides in agriculture at the end of the 1950s. At that time, the national volume of pesticides used was about 100 tons (ANH 2002). In the 1980s, there were about 20 types of active ingredients used in agriculture in Vietnam, among which Aldrin, Dieldrin, Heptachlor, Lindane, Methamidophos and Methyl-parathion were the most common ones. Following economic liberalization, farmers have been allotted agricultural land and given rights to make decisions over their farming practices, and private actors have been allowed to participate in pesticide import and distribution. This has led to a remarkable increase in pesticide use in agriculture in Vietnam. For instance, between 1990 and 1999, the average volume of pesticides used per ha of agricultural crops increased more than 100 per cent (ANH 2002). This trend has continued up till now, along with increased imports of pesticides, i.e., from 33,700 tons in 1999 to 76,000 tons in 2007 (ANH 2002, VINACHEM 2008). In parallel, the number of pesticide trade names increased from 837 in 1999 to 3,019 in 2008 (MARD 2008).

Currently, Vietnam has used 292 different insecticides, 221 fungicides, 130 herbicides, (MARD 2008). Though being restricted in use, organophosphates which are in the WHO hazardous categories I and II, are applied by a larger number of farmers. All farmers used pesticides of all kinds to control pests. In addition, with greater market liberalization there is higher tendency to use cheaper, more hazardous pesticides. There is less conformity to guidelines issued by the Department of Plant Protection.

The increased use and misuse of pesticides is particularly worrying for human and environmental health. TRAN *et al*. (2005) found that with market liberalization "there has been a greater tendency towards the application of cheaper, more hazardous pesticides and less conformity to the guidelines issues by the Plant Protection Department".

A study by NGUYEN and TRAN (1997) found that farmers in the Mekong Delta overuse pesticides, including several products that have either been banned or restricted because of their toxicity. Further, it was found that even if farmers can read the pesticide labels, they do not always follow the instructions or use protective clothing, resulting in pesticide exposure and poisonings. It has also been found that while poorer farmers apply lesser amounts of pesticides than better off farmers, they use more toxic pesticides.

Among the agricultural crops, vegetables are the most vulnerable to pests and diseases. Most of the vegetables produced require a good appearance to attract consumers. This requirement causes vegetables to be subjected to more pesticide treatments as compared to other crops. In addition, most farmers use pesticides intensively, much more than instructed on the labels (ANH 2002). Intensive and improper pesticide use on vegetables in the field results in high pesticide residues on products. More than 28% of vegetable samples collected in Hanoi had pesticide residues that were two to six times higher than the maximum residue level. Vegetables have been thus considered the most dangerous food by Vietnamese consumers (FIGUIÉ 2003).

Annually, thousands of Vietnamese consumers are poisoned by food contaminated with chemicals. Besides acute poisoning due to direct and indirect exposure to pesticides, chronic pesticide poisoning could affect millions of Vietnamese farmers. In Vietnam, the annual cost of pesticide-related domestic human health and of lost export opportunities for vegetables and fruits remains very high. Besides human health, pesticide use also endangers water quality and ecosystems in the fertile river deltas in northern and southern Vietnam (BERG 2001). Pesticides lead to a loss of species, to changes in food webs and as a result to an increase of algae biomass (BRINK and SURESHKUMAR 2003).

The overuse of chemical fertilizer not only leads to decreasing fertility of the soil - the compact and infertile situation, but also the capacity of growth and resistance of the plants to outside disadvantageous conditions (like climate change, fungus levels and pests...) will be decreased and farmers should obligatorily apply chemical pesticide to protect their crops. In conclusion, agricultural products will be low of quality. Many people life are harmed by food poisoning.

1.2. Problem statement

Vietnam is a South East Asia country has total land area of about 331.15 square kilometers, and has a tropical monsoon climate. The country is elongated from North to South with an eastern coastline of 3,200 kilometers, stretching from latitude $8^{\circ}02^{'}$ to 23° 03’ North. The population is about 86.93million people and is continuing to grow at about 1.05% per annum. 69.83% of population lives in rural areas and engages in agriculture (GSO 2011), which means that agricultural production plays an importance role in Vietnam, and 16.06% live in two key cities, Hanoi and Ho Chi Minh City (GSO 2011).

In 2010, the total area of land used for agriculture was about 9.420 million ha, of which 6.309 million ha was annual crops (4.105 million ha rice production, 2.147 million ha cash crops, and 0.561 million ha grass production), and 3.111 million ha used for perennial crops. The number of farms has increased quickly in all regions in the whole country (GSO 2009). In 2007, there are 116,222 farms in Vietnam, increasing 2,523 farms (+2.22%) in comparison with the year 2006. The Mekong River Delta, the South East regions and the Red river Delta are regions having most of the farms since there is plenty of land and water surface to expand the scale of plantation, animal husbandry and aquaculture production. There are 86,626 farms in these three regions, accounting for 74.54%; only Mekong River Delta accounts for 47.34% of farms in the whole country. Farming production is more and more diversified and there is a reducing percentage of annual and perennial crop farms but increasing farms of animal husbandry, aquaculture and production-business combination. The percentage of annual crops farms have reduced from 34,224 farms (29.93%) in 2005 to 33,293 farms (27.79%) in 2007; perennial crop’s farms from 27.2% to 20.1%; animal breeding farms have increased from 2.9% to 14.6%; aquaculture farms are from 27.9% to 29.6% accordingly (GSO 2007 and GSO 2008).

Urbanization and industrialization lead to rapid changing environmental conditions along urban-rural interfaces. This makes direct impact people who are involved in urban or peri-urban agriculture. Nowadays, the vegetable demand pressure in and around urban areas, mainly because people in urban areas depend to a much large extent on market supplies for their food consumption than rural people, and urban regions usually have higher income and exhibit faster income growth than rural areas. While almost Vietnamese family in rural areas maintains a little garden for subsistence, but differs from urban areas (XUAN and TIMMER 1990 cited by JANSEN *et al*. 1996). Furthermore, the urban population in Vietnam has grown at an annual rate of nearly 3.31% during the past decade, compared to an overall population growth of about 1.32% per year (GSO 2009). Current population growth in Hanoi is estimated to exceed 1.31% per year (HSO 2009). Urban, peri-urban, and rural agriculture in Hanoi could only supply 44% of the city's demand in 2001. In particular, rice and vegetables met 40% and 60% of the demand in 1999, respectively (HDARD 2000).

Vietnam still ranks among the lease developed countries in the world. Estimated GDP per capita in 2010 was measured at USD 1,111.6 for the whole country. Agricultural production output value, including forestry and fishery is about 20.58% of GDP, industrial production about 41.09%, trade and services about 38,33% of GDP (GSO 2011).

The nutritional status of the Vietnamese population has been described as extremely low, resulting in serious degradation of the human capital resources (ANONYMOUS 1989, XUAN and TIMMER 1990 cited by JANSEN *et al*. 1996). Improving nutrition levels receives high priority in the social development program sponsored by international agencies (ANONYMOUS 1994 cited by JANSEN *et al.* 1996). Vitamin A and micro-nutrient deficiencies were singled out as particular serious, pointing to the importance of increasing availability of vegetable (ALI and TSOU 1996).

The foodstuff safety has always been considered very important, especially vegetable production. The Vietnamese government, as well as many other organizations, is working to make vegetable production less harmful to consumers and the environment. Initiatives such as FAO's Regional Asian Vegetable IPM programs and a similar initiative by the Hanoi Farmer Union have focused on increasing farmers' knowledge of the use and effects of chemical pesticides. In 1996, Hanoi's Department of Science, Technology and Environment developed a protocol for "safe" vegetable production and set up a "safe vegetable" certification programme, which allowed farmers and cooperatives to supply state-run "safe" vegetable shops and supermarkets. A "safe" vegetable is still produced using agrochemicals, but farmers take care not to use forbidden pesticides and to reduce the amount.

In 1998, Ministry of Agriculture and Rural Development (MARD 2008) issued the "Temporary Regulation for the Production of Safe Vegetables" which was then finalized in January 2007 as the "Regulation for the Management and Certification of Safe Vegetable Production" (No.04/2007/QD-BNN). It was later replaced in November 2008 by Decision no 99 titled "Management of safe vegetables, fruit and tea production and trading." These regulations introduced guidelines for safe vegetable production as well as tables showing the maximum residual levels for permitted pesticides, nitrate, heavy metals, bacterial pathogens and intestinal parasites, which are allowed in soil and in harvested vegetables. Many other decisions were promulgated by the government to guide and support safe vegetable production. The government followed the policy initiatives by offered training to farmers on safe vegetable production and integrated pest management (IPM) in an effort to improve food safety. In Vietnam, farmers started to introduce an adopted regulation for production of fresh fruit and vegetables in Vietnam (VIETGAP). The hazards covered in VIETGAP include food safety, produce quality, environmental impacts and health, safety and welfare for Vietnamese workers (MARD 2008).

Although guidance on the safety of vegetable production has been given, it is difficult to know whether such guidance is followed or not. Thus, safety vegetables may be "not safe enough" (RAUHOAQUAVIETNAM 2007). To increase productivity in agriculture and horticulture, often higher intensification and increasing amount of fertilizers and pesticides were used by the Vietnamese farmers in order to increase the yield. However, chemical fertilizer, pesticides have negative health effects on the actors directly or indirectly involved in the food supply chain (such as farmers, traders, and consumers) especially when pesticides are improperly applied. The research of UGA *et al.* (2009) revealed that the vegetables purchased at a suburban market in Hanoi were highly contaminated with parasite eggs. A study has done by the Institute for Ecology and Biology Resources in 1998-1999 found nitrate levels from fertilizer use much higher than maximum residue levels in commercial vegetable products in peri-urban of Hanoi (cited by BENOIT and NAM 2009). Toxic pesticides have caused many food poisoning scandals in Vietnam. From 2006 to 2010, more than 944 cases of food poisoning from direct and indirect exposure to pesticides do not include the numerous cases of 'silent' casualties by pesticides from pesticide residues (involving 33,168 people) were reported, causing 259 deaths (NIN-UNCF 2011). Especially, in peri-urban areas such as Hanoi where the majority of vegetables are produced, over-use of chemical fertilizers and pesticides as well as toxic waste from large industries has resulted in severe soil contamination and environmental pollution (ANH *et al*. 2004).

The living standard of the Vietnamese people has increased significantly, and the demand for fresh vegetables has increased in line with the standard of living. Nevertheless, most of the vegetable farmers in Vietnam often become trapped in a cycle of ever-higher chemical usage (LAODONG 2007). Therefore, to carry out the research to access the sustainability of vegetable cultivation systems in order to understand the characteristics of the existing vegetable cultivation systems, type of training, education, and attitude do the farmer's possess on their vegetable farm and what are the direction vegetable productions in terms of both the qualitative, quantitative, and environmental sustainability are compulsory.

Ideally, policy decisions should coincide with the results of scientific analysis, however, because of conflicting interests this is frequently not the case. On the one hand, policy decisions are embedded in a cultural environment that is shaped by rational and by irrational traditions, by ethical consensus and by discourse. In a modern society, on the other hand, policy decisions are based on scientific analysis, apart from the normative aspects. Thus, relating scientific sustainability assessment to the cultural, ethical, and political context, it becomes apparent that scientific sustainability assessment can contribute significantly to policy decision making, but that it is not the only basis for such decisions (BARBARA 1997). In this study, three sustainable assessment approaches are chosen based on the theoretically well founded, clear in content, can be easily measured, compared, financial limitation, time limiting and it can be regionally specific adapted. In order to guide a decision-maker in choosing the most appropriate sustainable assessment approaches to apply.

The criteria for focusing the studies on the Red River Delta:

- The demand for vegetable increased in this region. Therefore, the production of vegetables becomes a higher importance in the agricultural sector in particular in North Vietnam.
- The vegetable supply for the very high population in RRD can be realized only by vegetable production in urban, peri-urban and rural areas.
- Besides the necessity to improve the productivity in vegetable production also the quality guarantee is of increasingly importance.
- The sustainability assessment of vegetable cultivation systems has not been carried out and studied systematically.

1.3. Organization of the study

This dissertation consists of nine chapters. Following current chapter, chapter 2 reviews and integrates the current literature that is relevant to the role of vegetable, sustainable agriculture and sustainability assessment in order to develop a framework for assessing the sustainability of vegetable cultivation systems. Chapter 3 reviews the general information about Vietnam and the study area. The country's profile, including economic growth and structure; the agricultural sector particularly those changes relating to the agriculture in Vietnam to provide a national context. Especially, information relates to the study area such as soil characteristics, change of agricultural land use, and vegetable production. Chapter 4 describes the specific aims, research questions, objectives, research hypotheses and the usefulness of the study. Chapter 5 presents the research methodology. In this chapter the research framework, the method for collecting data, data management and data analysis, rational for the choice of sustainable indicators and the choice of sustainability assessment method are expressed in detail. In chapter 6 present the results from primary and secondary data collection such as the land resources, human resources, and characteristics of the vegetable cultivation systems in the study area. The results of the financial analysis and synthesizing of sustainable indicators of vegetable cultivation systems in the study area are represented. Chapter 7 presents the results of the sustainability assessment, the sensitive analysis of the vegetable cultivation systems in the study area and discussion on the finding. In chapters 8, the results of the study are summarized and some conclusions are given. Finally, limitations, suggestions for further studies and some recommendations to the farmer and decision maker, researcher, and other related institutions involved to vegetable sector are presented in the chapter 9.

2. LITERATURE REVIEW

"Agriculture plays a crucial role in addressing the needs of a growing global population, and it is inextricably linked to poverty eradication, especially in developing countries… Sustainable agriculture and rural development are essential to the implementation of an integrated approach to increasing food production and enhancing food security food safety in an environmentally sustainable way"

(Paragraph 40 of the Plan of Implementation of World Summit on Sustainable Development, WSSD 2010)

This chapter starts with definitions and review of sustainability and sustainability in agriculture. Different dimensions of sustainable agriculture are briefly described. It then moves to core issue of this study, which is sustainability assessment definition, review, the sustainability of vegetable farming systems and its development, the roles of vegetable in our daily life are discussed. The chapter also reviews the vegetable production in some selected countries in South East Asia and in Vietnam.

2.1. Sustainability and sustainable agriculture

2.1.1. Sustainability definitions and review

"There are many definitions or, better, descriptions of sustainability according to subject" (BARBIER 1987; COSTANZA 1991, COMMON and PERRINGS 1992, DOVERS 1990, HARRISON 1992, OPSCHOOR and VAN DER STRAATEN 1993, WCDE 1987 cited by YANNIS and ANDRIANTIATSAHOLINIAINA 2001). The concept of sustainability has its roots in forestry, fisheries, and range management. The most commonly agreed upon German equivalent term, Nachhaltigkeit (sustainability), was introduced in forestry by the miner von Carlowitz in the eighteenth century (PETERS and WIEBECKE 1983, BML 1995 cited by BARBARA 1997) to describe the maintenance of long-term productivity of timber plantations to continuously provide construction poles for the mining industry. This use of the term was driven by the same political interest in economic growth as the World Commission on Environment and Development (WCED 1987) report 200 years later.

The Brundtland Commission, formally known as the World Commission on Environment and Development (WCED 1987), this report emphasized the economic aspects of sustainability by defining sustainable development as "economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs". This combination of sustainability and development tries to reconcile economic growth in the neoclassical tradition with a new concern for environmental protection, recognizing the biophysical "limits to growth" (MEADOWS et al. 1972 cited by BARBARA, 1997) as a constraint to economic development. The term sustainability was also used in the CGIAR's mission statement in 1989 to mean "successful management of resources for agriculture to satisfy changing human needs while maintaining or enhancing the quality of the environment and conserving natural resources" (BARBARA, 1997).

Earlier use of the term sustainability in ecological and agricultural literature had hardly been noted outside the scientific community directly involved. The term sustainability was used in the context of productivity, either as a descriptive feature of ecosystems, "sustainability is the ability of a system to maintain productivity in spite of a major disturbance (intensive stress)" (CONWAY 1983), or as "sustainable yield" of agricultural crops (PLUCKNETT and SMITH 1986).

Sustainable agriculture includes agriculture that is economically viable, socially just, culturally appropriate, and environmentally sound and has been enduring productivity. Agro-ecology also embraces these dimensions while emphasizing the ecological principles and the interrelatedness of agro-ecosystem components (ALTIERI 2003). In terms of agro-ecosystem sustainability, GLEISSMAN (2001) remarks that the challenge has been to identify the levels and conditions of specific parameters of agro-ecosystems that must be maintained for sustainable function.

GARY *et al.* (2005) describes sustainability in terms of concentric circles (Figure 2.1), where the environment is ultimate setting within which societal structures are built, and society itself is more fundamental than the economic constructions that humans design and implement. Yet, in this representation too there are interconnections, as shown by the double-headed arrows between each of three components of sustainability. Most important here is the emphasis on the primacy of the environment. While the economic and social systems evolve and change - sometimes with the development of organizational structures that fail and are replaced-every society and systems is built and lives within the diverse surroundings of the Earth. Every human-created form of sustainable society requires that the integrity of the environment be upheld.

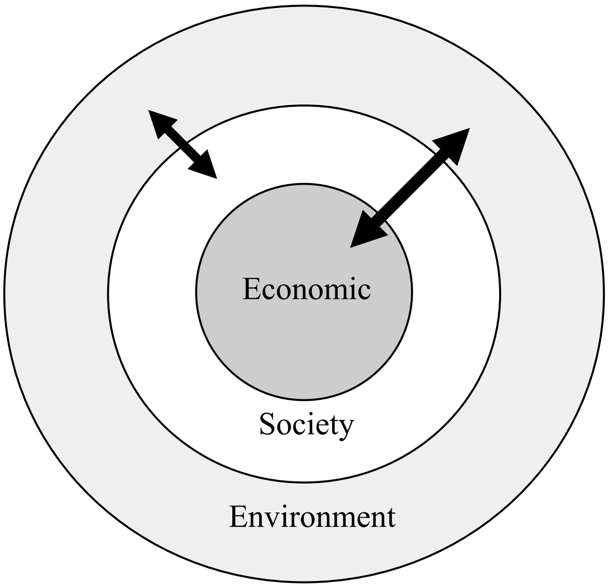

Figure 2.1. Components of the sustainability tripod placed in a hierarchy relationship. Environment holds primacy as ultimate limiting factor and vibrant economy is reliant on a 'healthy' society and environment (Adopted from GARY et al. 2005)

These types of definitions represent the most common approaches; that is, economic, ecological, and holistic sustainability concepts, which are equivalent to the categories: Sustainable Growth, Agro-ecology, and Stewardship, as suggested by HARRINGTON (1993) and RUTTAN (1994).

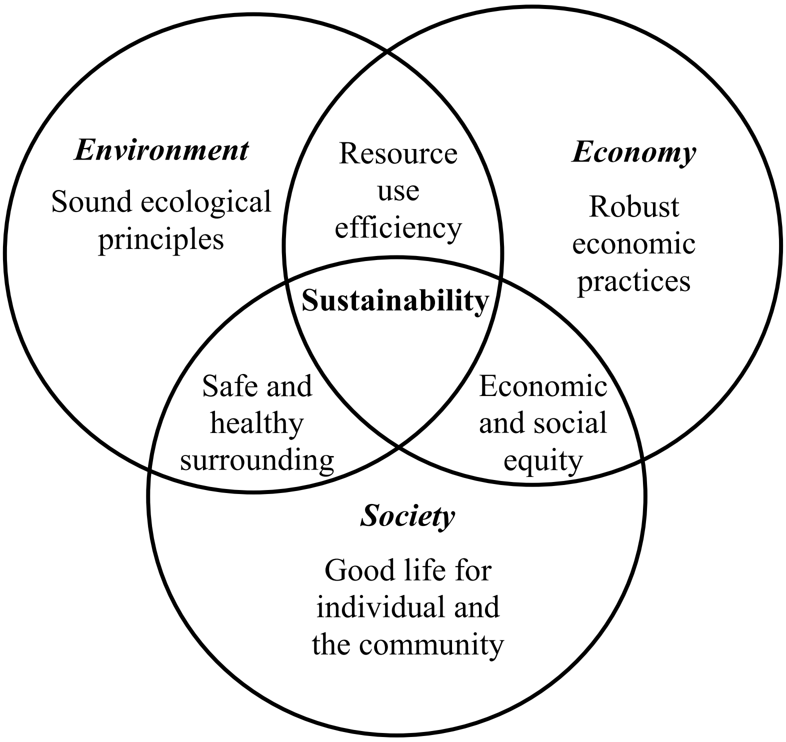

Figure 2.2. The sustainability tripod, showing the interrelations between the components of Environment, Economy and Society (Adopted from GARY et al. 2005)

A comprehensive view of sustainable should incorporate three elements: environmental, economic, and social (GARY et al. 2005). There elements have its relationship as sustainability tripod (Figure 2.2) and each component is interconnected with the others. It is only when we consider all three components together as a group, that we have assessed sustainability in comprehensive terms. There are alternative diagrammatic representations that attempt to illustrate other aspects of the relation between the three essential components of sustainability.

2.1.2. Sustainable agriculture

Excessive and unbalanced use of agro-chemicals has led to increased production costs and dependence on external inputs and energy, decline in soil productivity, contamination of surface and ground water, and adverse effects on human and animal health (EDWARDS 1989, and BISWAS 1994). Therefore, there is growing emphasis on sustainable agriculture in concerning with the adverse environmental and economic impacts of conventional agriculture (HANSEN 1996). In contrast, sustainable agriculture is viewed as low-input and regenerative (O'CONNELL 1991), which makes better use of a farm's internal resources through incorporation of natural processes into agricultural production and greater use of improved knowledge and practices. It uses external and non-renewable inputs to the extent that these are deficient in the natural environment (PRETTY 1995).

In terms of agriculture, sustainability has many meanings (SMIT and SMITHERS 1993, 1994), most definitions are fundamentally similar. Consider representative definitions of sustainable agriculture: Agri-food systems that are economically viable, meet society's need for safe and nutritious foods, while conserving natural resources and the quality of the environment for future generations (SCIENCE COUNCIL of CANADA 1992).

Agricultural system that can indefinitely meet demands for food and fiber at socially acceptable economic and environmental and these definitions suggest that sustainability implies (1) meeting human needs for food and fiber, (2) conserving environment or natural resources, and (3) maintaining economic viability costs (CROSSON 1992 cited by SMIT and SMITHERS 1993).

Despite the diversity in conceptualizing sustainable agriculture, there is a consensus on three basic features of sustainable agriculture. These are: (1) maintenance of environmental quality, (2) stable plant and animal productivity, and (3) social acceptability. Consistent with this, YUNLONG and SMITH (1994) have also suggested that agricultural sustainability should be assessed from the perspectives of ecological soundness, social acceptability, and economic viability. ‘Ecological soundness’ refers to the preservation and improvement of the natural environment. ‘Economic viability’ refers to maintenance of yields and productivity of crops and livestock, and ‘social acceptability’ refers to self-reliance, equality and improved quality of life.

Sustainable agriculture is a philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. Use of this philosophy guides our application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems. These systems reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term, and maintain stable rural communities and quality of life (CHARLES and GARTH 1990).

Sustainable agriculture does not refer to a prescribed set of practices. Instead, it challenges producers to think about the long-term implications of practices and the broad interactions and dynamics of agricultural systems. It also invites consumers to get more involved in agriculture by learning more about and becoming active participants in their food systems. A key goal is to understand agriculture from an ecological perspective in terms of nutrient and energy dynamics, and interactions among plants, animals, insects and other organisms in agro-ecosystems, then balance it with profit, community and consumer needs (SARE 1997).

STEPHEN (1998) confirmed sustainable agro-ecosystems that: maintain their natural resource base; rely on minimum artificial inputs from outside the farm system; manage pests and diseases through internal regulating mechanisms; recover from the disturbances caused by cultivation and harvest.

The term sustainable agriculture means an integrated system of plant and animal production practices having a site - specific application that will, over the long-term (OLRC 2012):

(1) Satisfy human food and fiber needs;

(2) Enhance environmental quality and the natural resource base upon which the agriculture economy depends;

(3) Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;

(4) Sustain the economic viability of farm operations; and

(5) Enhance the quality of life for farmers and society as a whole.

Sustainable agriculture is "a way of practicing agriculture, which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, environmental protection, and consumer safety. It is achieved through management strategies, which help the producer select hybrids and varieties, soil conserving cultural practices, soil fertility programs, and pest management programs. The goal of sustainable agriculture is to minimize adverse impacts to the immediate and off-farm environments while providing a sustained level of production and profit. Sound resource conservation is an integral part of the means to achieve sustainable agriculture" (OLRC 2012).

O'CONNELL (1992) defines "Today, sustainable farming practices commonly include:

- Crop rotations that mitigate weeds, disease, insect and other pest problems; provide alternative sources of soil nitrogen; reduce soil erosion; and reduce risk of water contamination by agricultural chemicals.
- Pest control strategies that are not harmful to natural systems, farmers, their neighbors, or consumers. This includes integrated pest management techniques that reduce the need for pesticides by practices such as scouting, use of resistant cultivars, timing of planting, and biological pest controls.
- Increased mechanical/biological weed control; more soil and water conservation practices; and strategic use of animal and green manures
- Use of natural or synthetic inputs in a way that poses no significant hazard to man, animals, or the environment.

These definitions have since been expanded to a comprehensive (yet hardly quantifiable) holistic concept (e.g., by the non-governmental organization treaty in an unpublished draft report) "Agriculture is sustainable when it is ecologically sound, economically viable, socially just, culturally appropriate and based on a holistic scientific approach" (cited by BARBARA 1997). Although this type of definition has been rejected as too vague by some scientists, it reflects the concern of many environmentalists and development agents not to separate society and environment; economy and ethics (SPENDJIAN 1991).

Although there are literally hundreds of definitions of sustainable agriculture, one of the more widely accepted definitions, developed by the United States Department of Agriculture is "a way of practicing agriculture which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, environmental protection, and consumer safety"(O'CONNELL 1992).

2.1.3. Farming systems and sustainability of vegetable farming systems and its development

2.1.3.1. Farming systems and farming systems research

A farming or land-use system is a complex unit of inter-related combinations of inputs, managed by farming households and influenced by environmental, biophysical, political, institutional, socio-cultural and economic factors that operate at various levels (i.e. community, district, regional). Farm households attempt to manipulate these factors in order to meet their needs, goals and priorities (CALUB and MAHATHIRATH 2009).

A farming system covers not only plantation and livestock, a collection of crops and animals. It involves other notable elements of the soil, the tools, the workers, natural environment and others that altogether are utilized by the farmer who mainly follow his individual preference and aspiration in producing farm product, for instance, vegetable. This means that the supporting input and technology applied by the farmer will resolve his profit. His unique perception towards the immediate environment, both natural and socio-economic, brings up his farming system (ADNYANA 1999).

Farming systems are closely linked to livelihoods because agriculture remains the single most important component of most rural people's living and also plays an important role in the lives of many people in peri-urban areas. Farming systems involve a complex combination of inputs, managed by farming families but influenced by environment, political, economic, institutional and social factors (NRI 2002).

Farming systems research is an approach to agricultural research. By examing farmers thoroughly, the system aims to identify the connection and interaction of different components of household members and their physical, biological and socio-economic environment (SHANER *et al.* 1982). This approach delivers problem solving by farmer orientation to the agricultural study with the comparison between the economic and environmental effect of different commodities. Such study with farming system perspective focuses on real problems of farmer with limited or poor resources, produces a linkage between farmer and researcher and delivers feedback to both planning research and priority setting process (SPENCER 1991).

The farming systems research also identifies the opportunities to improve the productivity of target groups, i.e. recommended domain, by understanding the production problems, current production practices and circumstances that influence farmer's option of technical scheme and production. Conducting technology test and development within the farming scope and demonstration is beneficial (LOW and WADDINGTON 1991).

There are eight broad categories of farming system proposed by FAO (2000) as follows:

1. Irrigated farming systems, embracing a broad range of food and cash crop production;
2. Wetland rice based farming systems, dependent upon monsoon rains supplemented by irrigation;
3. Rainfed farming systems in humid areas of high resource potential, characterized by a crop activity (notably root crops, cereals, industrial tree crops – both small scale and plantation – and commercial horticulture) or mixed crop-livestock systems;
4. Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock systems;
5. Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock and pastoral systems merging into sparse and often dispersed systems with very low current productivity or potential because of extreme aridity or cold;
6. Dualistic (mixed large commercial and small holder) farming systems, across a variety of ecologies and with diverse production patterns;
7. Coastal artisanal fishing, often mixed farming systems; and
8. Urban based farming systems, typically focused on horticultural and livestock production.

In spite of eight farming system categories defined by FAO (2000), KAVETSKIY *et al.* (2003), classify the farming system in to broad groupings, describes as follows:

1. Intensive farming system- crop yields are raised through increased input of labor and capital in the form of mechanization, use of nutrients, protection against pests and often irrigation.
2. Extensive farming system- is farming practices where purchased inputs are kept at a minimum. The difference between intensive and extensive system is one of economy rather than principles, the preferred systems depending on local conditions.
3. Traditional farming system- is farming based on local traditions with little use of advisory services. Farms have a low degree of mechanization and are often less intensive than conventional systems.

4. Conventional farming system - is practiced in accordance with general recommendations from local or regional advisory services. Nutrients are applied in accordance with fertilizer plan based on soil analysis, previous field history, farmer's experience and regional field trial.
5. Integrated farming system- aims to obtain high yield while keeping close control over inputs. It is more knowledge intensive, marking greater demand on the individual farmers. Nutrients are applied with careful attention to timing and crop needs, sometimes resulting in somewhat reduced application rates compared to conventional system.
6. Organic farming system- it differs from conventional and integrated farming mainly in that it rejects the use of most fertilizers and pesticides. It is often considered being extensive. Organic agriculture is a general term for such systems. The ideal is a self-sustaining, balance vegetable based on local and renewable resources.

2.1.3.2. Sustainability of vegetable farming systems and its development

According to FAO (2004), vegetable farming systems is sustainable when it is ecological sound, economical viable, social just, culturally appropriate, long term production, humane and based on holistic scientific approach (FAO 2004).

BUDIANTO (1999 cited by ARSANTI 2008) defines sustainable vegetable farming systems as the use of renewable resources and non-renewable resources for vegetable production process in efficient way by minimizing the negative impact towards environment. The sustainability includes resource utilization, the quality and quantity of the production and the environment. The vegetable production process, therefore, will use biological products, which are environmental friendly.

Another definition that effectively defines sustainable vegetable farming systems is a vegetable farming system that can evolve indefinite toward greater human utility, greater efficiency of resources use and a balance with the environment that is favorable to humans and to most other plants and animal (HARWOOD 1990).

Sustainable vegetable farming systems emphasize on the need for environmental protection and ecological balances. It is important to use natural substance such as composted fertilizer, organic fertilizer instead of synthetic chemical such as chemical fertilizer, pesticide, hormone… Meanwhile, the economic side is not neglected as a method of farming is not profitable, it cannot be sustainable (MADDEN 1988).

Food 2000 Global Policies for sustainable agriculture (HANSEN 1996) stated the sustainable vegetable farming systems stressed the need for the reserving the resource base of vegetable productions. Enduring food security will depend on a sustainable and productive resource base. The challenge faced by the government not increase vegetable productivity and ensure food security, while enhancing the productive capacity of this manual base resource in a sustainable manner. There are two interpretations of vegetable farming systems sustainability. Firstly, the sustainability is interpreted as an approach to vegetable farming systems development in response to the concern on agriculture impacts. Secondly, the sustainability is interpreted as a property of vegetable farming systems development in response to the concern on agriculture threats, by applying this as criteria for vegetable farming systems guidance as it responds well to the changes (HANSEN 1996).

It is important factors need for sustainable vegetable farming systems is political and social stability that can enhances farm cycles and stable land use systems, encourages investment and social services. In other hand, it is important to ensure development activities by the participation of the involved communities. The communities should contribute their thoughts for the development objectives, thoroughly involve in, and commit to the implementation. Special care is needed to identify and meet the needs of women and ethnic minorities Participant by local communities will minimize the danger of inappropriate approaches and employed technology. Also, it is important that the appropriate policies and institutional capacity to carry out development task and support development. Institution is open to the public sectors and private sectors as well as the non-governmental organizations and informal institutions in showing their capacity, aptitude and ingenuity in handing the challenge.

Another important factor for sustainable vegetable farming systems is to develop human resources through education and training programs. The knowledge and skill of the country's human capital is a vital ingredient in initiating and sustaining development in agricultural sector in particular.

The means to archive sustainable vegetable farming systems are associated with good practices related to people centered development, sustainable livelihoods, sound agro-ecological practices, sustainable forestry system, community based natural resources management, participatory policy development, indigenous farming system, fair labor condition, good agricultural practices, equitable access to water and others (ARSANTI 2008).

2.2. Sustainability assessment definition and review

''Sustainability assessment is a tool that can help decision-makers and policy-makers decide what actions they should take and should not take in an attempt to make society more sustainable'' (DEVUYST 2001).

POVEDA and LIPSETT (2011) pointed out: throughout the assessment process, decision makers encounter a large number of choices. First and foremost, decision-makers must decide on which sustainability assessment approach meets the needs of a specific project, and how sustainable development goals are to be met. In assessments, the decision-makers are faced with critical decisions that affect the project in some way. A sustainable choice could affect the budget, risk assessment, schedule, and other factors in a project; and project factors can influence a sustainability choice. The uniqueness of particular projects makes decision making more challenging. Furthermore, sustainability assessments should be more flexible in the sense of being more sustainability-focused decision making based on suitable sustainability principles. At times advocates for sustainability have taken matters into their own hands by drafting, testing, and listing a set of core criteria related to the decision, with sustainability as the ultimate goal.

VERHEEM 2002 confirmed that the aim of sustainability assessment is to ensure that ''plans and activities make an optimal contribution to sustainable development''.

It is widely accepted that a reliable measure of sustainability should be the result of integrating economic and natural resources accounts. However, this is not readily achievable due to lack of data and yet unsolved methodological problems (KAUFMANN and CLEVELAND 1995). In the field, especially in farming systems, sustainability is extraordinarily complex measure. Operationalizing sustainability on the ground involves considering numerous aspects, variously identified as physical, environmental, social, cultural and/or economic dimensions. This complexity leads to the need for integrated, interdisciplinary assessments that can consider the sum of its parts.

The fundamental principles of sustainability postulate the following: multidimensional approaches considering ecological, economic and social aspects at an equivalent level; a systematic investigation conceiving not only single factors but also complex functions and processes with various interactions between elements. This point of view entails also the assessment of sustainability with regard to a suitable temporal and spatial scale; a consensus based process of decision finding with special focus on ecological aspects of sustainability (GIAMPIETRO and BUKKENS 1992).

According to GIAMPIETRO and PASTORE (2000), agriculture operates on the interface of two complex, hierarchically organized systems: the socio-economic system and the ecosystem. So in any defined farming system one will always find legitimate and contrasting perspectives with regard to the effects of changes in the system, and the effects are not likely to result in absolute improvement for all stakeholders. Hence, a ‘correct’ assessment of agricultural performance should best be based on an analysis of trade-off that reflect the various perspectives, both positive and negative, with regard to the effects that a proposed technological or policy change will induce on the various scales and actors involved. A methodological tool, the AMOEBA multi-dimensional reading that can be used to characterize farming system performance in an integrated way on various scales and according to various perspectives.

There are 73 sustainability assessment methods, tools and procedures that are listed in the BEQUEST project including some rating system (cited by POVEDA and LIPSETT 2011).

Approaches commonly known by researchers in monitoring sustainability include environmental or extended cost-benefit analysis, multi criteria decision making (MCDM) and sustainability indicator analysis (MULLER 1997).

Pressure-State-Response (PSR): This model was developed by the Organization for Economic Co-operation and Development (OECD 1991) and is based on the fact that humans exert pressures on the ecosystem and the society which alter their state and call for certain responses. Its primary focus is on ecological aspects although socio-economic indicators are also of interest.

Ecological Footprint: It was introduced in REES (1992) and calculates the equivalent land needed to produce certain basic resources and absorb certain wastes associated with a given population. In short, the ecological footprint is the productive land that a population uses. It is biased towards the ecological side and computes a land area, not a sustainability score.

Barometer of Sustainability: This model was introduced by the International Union for the Conservation of Nature (IUCN) (PRESCOTT-ALLEN 2001) and is a visual tool of sustainability assessment. The sustainability of a country has two fundamental components, Ecosystem Well-Being and Human Well-Being. All indicators are scaled in [0, 100], where 0 is the worst performance and 100 the best performance of an indicator. Then scores are computed by a straightforward aggregation.

Environmental Sustainability Index (ESI): ESI (ESTY *et al.* 2005) computes an environmental sustainability index for a country based on 21 indicators, which in turn are assessed from 76 data sets. The ESI index is computed as a weighted average of indicators with equal weights. Countries are ranked accordingly.

Sustainability Assessment by Fuzzy Evaluation (SAFE): This model was introduced in PHILLIS and ANDRIANTIATSAHOLINIAINA (2001). SAFE is a hierarchical fuzzy inference system. It uses knowledge encoded into "if-then" rules and fuzzy logic to combine 75 inputs, called basic indicators, into more composite variables describing various environmental and societal aspects and, finally, provides an overall sustainability index in [0, 1].

Multiple Criteria and Fuzzy Logic: A model similar to ESI using 74 indicators and multiple-criteria decision-making (MCDM) in conjunction with a fuzzy inference scheme similar to SAFE was introduced in LIU (2007). It computes an aggregate sustainability index through sequential fuzzy reasoning while MCDM has three steps, decomposition, weighting, and synthesis.

Sustainable Society Index (SSI): The SSI (VAN DE KERK and MANUEL 2008) is based on 22 environmental and societal indicators that are aggregated into 5 main categories using equal weights. The 5 categories are then aggregated into SSI using unequal weights. In all 150 countries are ranked accordingly.

2.2.1. Rational for the choice of sustainable indicators

For any study on sustainable agriculture, the question arises as to how agricultural sustainability can be assessed. Some argue that the concept of sustainability has yet to be made operational (WEBSTER 1997). Indicators can be considered to be variable, parameter, signal, statistic, measurement, medium, experiential model, and so on, and are a concise denotation for complicated systems with a variety of functions such as reflection, estimation, premonition, and instruction (RIGBY *et al.* 2001). The indicators selected in terms of the scientific method can reliably reflect the state, development, and function of the systems. Sustainable indicators are the outcome of the human sustainable development practices, which reflect human's deepening cognition on nature, and the embodiment of the human subjective motivation and desire, and their development has been unceasingly promoting the practice of sustainable development.

As for the selection criterion of indicators, the Minister of Agriculture, Fisheries and Food of England required that it should have policy relevance, analytical soundness, measurability, appropriate aggregation level, and be representative of social desirability (MAFF 2000).

The Environmental Protection Agency of America proposed that indicators must be closely and unambiguously related to the assessment goals, and are important to the overall structure and function of the agro-ecosystem, and must be responsive to a range of environmental stresses (MEYER *et al.* 1992). Besides the above, these must be simple, cheap, easily explainable, not redundant, with little variation, and of historical data (BELLOWS 1994, HERRICK 2000).

FAO presented five steps to determine sustainable indicators (cited by BOSSEL 1999, GARCIA *et al.* 2000):

- Specifying the scope of the sustainable development reference system;
- Developing a framework to agree on components within the system;
- Specifying the criteria, objectives, potential indicators, and reference values;
- Choosing the set of indicators and reference values; and
- Specifying the method of aggregation and visualization.

Sustainability indicators are those relevant, reliable, quantifiable data that reflect the sustainability of a system. Selection of indicators is based on properties that are desired within a given system. It is from those indicators (what we must achieve) that practices (how we can achieve it) can be identified for either maintaining a functioning system or progressively moving a system toward those indicators. In recent years, an enormous effort has gone into developing and identifying sustainability indicators for agricultural systems and agro-ecosystem health by scientists, development specialists and planners to assess the status of the environmental, social and economic components. By linking indicators that reflect social, economic and environmental parameters, sustainability footprints for various systems can be developed (GOMEZ 1996).

Further and within the development arena, there is some controversy regarding how indicators are derived particularly given the potential for external biases to drive indicator development without addressing the considerations of local people (NAZAREA *et al.* 1998).

WATTENBACH and FRIEDRICH (2002) have presented a case study based on work in Tanzania that identifies indicators of sustainable farming systems using a combination of quantitative and qualitative data. They note that indicators must be at a level higher than field level but lower than agro-ecological zone and that indicators must consider the farmers decision making processes concerning their resource management taking into account the socio economic sphere shaping farmers' behavior. These efforts point to the importance of articulating universal indicators and those contextualized to a specific setting.

BELLOWS (1994) suggested that setting up the sustainable indicators system must include the entire process from motive, designing, to final acting and feedback. The content of the indicators system is different from each other for different countries, regions, and development stages, and is of great subjectivity.

Although precise measurement of sustainable agriculture is not possible, "when specific parameters or criteria are selected, it is possible to say whether certain trends are steady, going up or going down" (PRETTY 1995).

According to LYNAM and HERDT (1989), sustainability can be assessed by examining the changes in yields and total factor productivity.

The workshop organized by the Institute for Low External Input Agriculture (ILEIA 1991) mainly emphasized productivity, security, continuity, adaptability and integrity as indicators of sustainability. BEUS and DUNLOP (1994) considered agricultural practices such as the use of pesticides and chemical fertilizers, and maintenance of diversity as measures of sustainability. For sustainable agriculture, a major requirement is the sustainable management of land and water resources. An International Working Group (SMYTH and DUMANSKI 1993) has concluded that the maintenance or enhancement of productivity, reduced risk, natural resources conservation, promotion of economic viability and social acceptability are essential conditions for sustainable land management.

GOWDA and JAYARAMAIAH (1998) used nine indicators, namely integrated nutrient management, land productivity, integrated water management, integrated pest management, input self-sufficiency, crop yield security, input productivity, information self-reliance and family food sufficiency, to evaluate the sustainability of rice production in India.

Despite a broad consensus about the basic features of agricultural sustainability, there are fewer consensuses about which components should be given more importance in the assessment of sustainability. Depending on their particular academic or professional backgrounds, different people emphasize ecological aspects such as maintaining agro-ecological health (CONWAY 1990), biodiversity (BOTHUN *et al.* 2000 cited by CLEMETSEN and VAN LARR 2000), integrated nutrient management (EDWARDS and GROVE 1991), and landscape quality, (CLEMETSEN and VAN LARR 2000, STOBBELAAR *et al.* 2000). Others, such as LYNAM and HERDT (1989), SMITH and MCDONALD (1998), and TISDELL (1996) attach importance to the economic aspects of sustainability, such as net present value, cost benefit ratio and profitability. Recently, DE JAGER *et al.* (2001) and TELLARINI and CAPORALI (2000) combined environmental and economic aspects in evaluating agricultural sustainability in Kenya and Italy respectively. However, few studies have assessed agricultural sustainability at the farm level covering all three main dimensions of sustainability.

Although many indicators have been developed, they do not cover all aspects of sustainability. Moreover, due to variation in biophysical and socio-economic conditions, indicators used in one country are not necessarily applicable to other countries. In Vietnam, where the majority of farmers are smallholders and average land holding size is less than 0.25 ha, farmers' immediate concern for agricultural development is how to increase crop yield, income, and food security and reduce the risk of crop failure.

Sustainability indicators were used in this research based on twelve criterions (Table 2.4) that cover three dimensions of agricultural sustainability and theoretically well founded, relatively stable and independent, clear in content, measurable and comparable, easy to quantify, regionally specific adapted, and based on acquirable data and can be grouped as hierarchical framework.

Table 2.1. Indicator for sustainability assessment in the study area

Ecological sustainability	**Economic sustainability**	**Social sustainability**
• Soil fertility (use of chemical fertilizer) • Soil fertility (use of organic fertilizer) • Cultivation of legumes • Management of pests and diseases (use of chemical control) • Human health	• Financial return • Index of yield trend • Efficient of market channel	• Input self-sufficiency • Employment • Access to credit • Access to agricultural extension

2.1.1.1. Ecological sustainability indicators

STUART (1992) emphasized that environmentally sustainable agriculture is compatible with and supportive of the following criteria for selecting most appropriate indicators:

1. Meeting the basic needs of all people, and giving this priority over meeting the greeds of a few;
2. Keeping population densities, if possible, below the carrying capacity of the region;
3. Adjusting consumption patterns and the design and management of systems to permit the renewal of renewable resources;
4. Conserving, recycling, and establishing priorities for the use of nonrenewable resources;
5. Keeping environmental impact below the level required to allow the systems affected to recover and continue to evolve (STUART 1992).

Base on five criteria for selecting most appropriate indicators STUART (1992), the ecological sustainability indicators has chosen such as:

- Soil fertility management including: use of chemical fertilizer (UCF); use of organic fertilizer (UOF). Several possible solutions to the environmental problems created by capital and technology intensive farming systems have been proposed and research is currently in progress to evaluate alternative systems (GLIESSMAN 1998). The main focus lies on the reduction or elimination of agro-chemical inputs through changes in management to assure adequate plant nutrition and plant protection through organic nutrient sources and integrated pest management, respectively (ALTIERI 1987). Because of the importance of organic fertilizers in replacement of agrochemical inputs, use of organic fertilizer in farming practices in the cropping systems is observed as an indicator of ecological sustainability. At that time organic manures were used in conjunction with inorganic fertilizers, and it may safely be assumed that rates at which organic manures were applied in the past would have been somewhat higher. Soil fertility management was evaluated based on the trend of farmer's using chemical and organic fertilizers. The trend of chemical fertilizers apply and the trend of organic fertilizers apply are considered to compare the sustainability between systems.
- Cultivation of legume crops (CLC): The vegetable root residues and green manure provide nitrogen mineralization for soil fertility improvement (CHAVESA *et al.* 2003, DE NEVE *et al.* 2003), specially legumes (plant in the family Fabaceae) have been used since antiquity as a primary nitrogen source across a range of agricultural and social settings. Legumes are utilized in agriculture because they enhance the productivity and potential sustainability of farming systems. According to

GREENLAND (1997), the amount of fixed nitrogen was between 20-120 kg/ha by grain legumes grown before or after the rice crop in rice-based cropping systems. Some benefits such as: N_2-fixation benefit, increased soil fertility and structure, decreased erosion risk, provide biodiversity, high protein, high value cash crop, reduced growth of weed species, break disease and pest life cycles, and capacity for high water use. The most important being the provision of N by symbiotic nitrogen (N_2) fixation. After carbon and water, N is often the most important limiting nutrient for plant growth (VAN KAMMEN 1997, VANCE 1997) and crop productivity (BOHLOOL *et al.* 1992, PEOPLES *et al.* 1995). The average area cultivate legume crops in cropping systems are considered to compare the sustainability between cropping systems.

- Management of pests and diseases - use of chemical control (UCC): yield and quality are central to sustainable vegetable production. If not properly managed, pests and diseases can dramatically reduce crop yield, quality and subsequent returns. Therefore, management of pests and diseases is very important indicator for sustainability assessment. Management of pests and diseases were assessed based on the proportion of farmers using biological, mechanical and chemical methods
- Human health: " Sustainable development can only be achieved in the absence of a high prevalence of debilitating diseases, while obtaining health gains for the whole population requires poverty eradication" (Paragraph 53 of WSSD 2010). There is clear linkage between farming's practice and human health as confirmed of USDA (2007) "potential health hazards are often tied to farming practices" especially with vegetable used as raw food diet. Farmers were asked to give their opinions about the health status of their family members and the frequency that they went to the doctor or went to hospital whether increasing or decreasing in last five year caused by diseases that related to their living environment, by chemicals used in agriculture or food poisoning.

2.1.1.2. Economic sustainability indicators

For economic sustainability of vegetable systems is financial return, yield stability and efficient of market channel were used as the indicators and can be detailed as follow:

- Financial return term (FR) in this study mainly focuses on cost - benefit analysis. Cost - benefit is an economic technique used. Cost - benefit analysis is a widely used tool for economic analysis for planning or evaluating a certain project or new technology. It is useful tool in which its main strength is an explicit and rigorous accounting framework for systematic cost efficiency decision making (KOPP *et al.* 1997). In other words, it can provide a transparent decision making framework that bring together estimates of the tangible and intangible benefits and cost of project, risks and uncertainties.

- Index of yield trend (IYT) is the most obvious indicator to assess the sustainability of agro-ecosystems (BARBARA 1997). Yield stability is the most important for economic viability of a system. A stable system or activity is not necessarily superior to an unstable one. Depending on relative costs/prices, an unstable activity may still be preferable to a stable one on grounds of long-run relative profit. But, other things being equal, stability will usually be chosen over instability, especially in subsistence situations where the goal is food rather than money. Modern farming systems in which yield maximization is a prime goal for farmers and breeders alike (EVANS 1993), in ancient and in current traditional farming systems a stable year to year yield is of prime importance and a major survival determinant. It is common knowledge that crop yields change as a function of environmental conditions.
- Efficiency of market channel (EMC) can be seen as a set of interdependent organizations involved in the process of making a product or service available for consumption or use. The process connects producers and final consumers and influences competition and prices within the market. JOHNSON *et al.* (1996) considers the link between the actors involved in the transformation of a good as a chain or a sequence where the different steps, through which a product must pass to reach the final consumer, are analyzed. In an agricultural context this typically means producing, collection, processing, storing, transporting, wholesaling and retailing of the good in question.

2.1.1.3. Social sustainability indicators

- Input self sufficiency (ISS) is an indicator of social acceptability. Sustainable agriculture should seek to minimize the dependency on external inputs (PRETTY 1995). Input self sufficiency was determined base on ratio of local input costs to the total input costs. The higher local inputs mean higher input self sufficiency.

- Employment (EPL) is an important indicator for assessing socio-economic development. Analysis of the changing dynamics of employment allows us to assess the impact of socio-economic transition and propose employment policies appropriate with socio-economic conditions of the nation. Vietnam's economy has undergone important changes in the past few decades, especially in the first decade of the twenty-first century. These important changes combined with improvements in education of the labor force in recent years have changed the structure and distribution of employed labor. This is very important criterion of social indicator. The trend of labors involved in their farming's practices in last five year was determined.
- Access to credit (AC) is importance indicator for agricultural development that is sources of providing capital for production and business activities. This is a reliable address to send money and convenient loan supports for people, actually better for farmers, especially poor farmers, helping to create jobs, poverty reduction. Farmer was asked to answer that they access to the credit "Yes", or do not access to the credit "No".
- Access to agricultural extension (AAC): Access to agricultural extension services is a promising strategy for increasing people's productive capacity resulting in the promotion of human development and poverty reduction (OECD 2001, WORLD BANK 2003 cited by KWAPONG *et al.* 2012). Extension services are widely used in both developing and developed countries (NORMAN *et al.* 1995, CHAMBERS 1997, FARRINGTON *et al.* 1997). Agricultural extension promoting agricultural development through technology transfer, from research institutions to the producers and connect producers to markets, establish relationships between producers, entrepreneurs, policy maker, and scientist. Interviewees were asked to answer that they have trained to approach the agricultural extension "Yes", or otherwise is "No".

2.2.2. Rational for the choice of sustainability assessment

2.2.2.1. Rational for the choice of sustainability assessment by multicriteria evaluation method

The multi-criteria decision analysis involves a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria. Criterion is considered a generic term that includes both the concepts of attribute and objective. Accordingly, two broad classes of multi-criteria decision making can be distinguished: Multi attribute decision making (MADM) and multi-objective decision making (MODM). Both MADM and MODM problems are further categorized into single-decision-maker problems and group decision problems. These two categories are, in turn, subdivided into deterministic, probabilistic, and fuzzy decisions. Deterministic decision problems assume that the required data and information are known with certainty and that there is a known deterministic relationship between every decision and the corresponding decision consequence. Probabilistic analysis deals with a decision situation under uncertainty about the state of problem's environment and about the relationships between the decision and it consequences. Whereas probabilistic analysis treats uncertainty as randomness, it is also appropriate to consider inherent imprecision of information involved in decision making; fuzzy decision analysis deals with this type of uncertainty. Conventional MCDM techniques have largely been a spatial in the sense that they assume a spatial homogeneity within study area. This assumption is unrealistic in many decision situations because the evaluation criteria vary across space. Consequently, there is a need for an explicit representation of the geographical dimension in multicriteria decision making (MCDM) (MALCZEWSKI 1999).

In general, MCDM problems involve six components (1) a goal or a set of goals the decision maker (interest group) attempts to achieve; (2) the decision maker or group of decision makers involved in decision making process along with their preferences with respect to evaluation criteria; (3) a set of evaluation criteria (objectives and or attributes) on the basis of which the decision makers evaluate alternatives courses of action; (4) the set of decision alternatives, that is, the decision or action variables; (5) the set of uncontrollable variables or states of nature (decision environment); and (6) the set of outcomes or consequences associated with each alternative-attribute pair (MALCZEWSKI 1999).

Multi-criteria methods of evaluation are gaining attention among the economic community (BANA 1990, NIJKAMP *et al.* 1990, VAN DEN BERGH and NIJKAMP 1991, MUNDA *et al.* 1994). Multi-criteria evaluation has demonstrated its usefulness in conflict management for many environmental management problems (MUNDA *et al.* 1994). The major strength of multi-criteria methods is their ability to address problems marked by various conflicting evaluations. In general, a multi-criteria model presents the following two aspects (GIAMPIETRO and PASTORE 2000):

- There is no solution optimizing all the criteria at the same time, and therefore decision making implies finding compromised solutions.

- The relations of preference and indifference are inadequate; when one action is better than another according to some criteria, it is usually worse according to others. Many pairs of actions remain incompatible with respect to a dominant relation.

Pairwise comparison method was developed by SAATY (1980) in the context of the analytic hierarchy process (AHP), this is a multicriteria decision making technique which decomposes a complex problem into a hierarchy, in which each level is composed of specific elements. The overall objective of the decision lies at the top of the hierarchy, then the criteria, sub-criteria and decision alternatives are on descending levels of the hierarchy.

Once the hierarchical model has been structured for the problem, the participating decision makers provide pairwise comparison for each level of the hierarchy, in order to obtain in the next higher level. This weighing factor provides a measure of the relative importance of this element for the decision maker (BÖHME 1986, LONG and BÖHME 2009, 2010, 2011, 2012a, 2012b).

NARASIMHAN (1983) identified the three advantages of AHP used as follow:

- It formalizes and renders systematic what is largely a subjective decision process and as a result facilitates 'accurate' judgement;
- As a by-product of the method, decision makers receive information about the implicit weights that are placed on the evaluate criteria, and
- The use of computers makes it possible to conduct sensitive analysis on the results.

Another advantage of using AHP is that it results in better communication, leading to a clearer understanding and consensus among members of decision making groups so that they are likely to become more committed to the alternatives selected (HARKER and VARGAS 1987).

AHP also has the ability to identify and take into consideration the decision maker's personal inconsistencies. Decision makers are rarely consistent in their judgements with respect to qualitative aspects. The AHP method incorporates such inconsistencies into the model and provides the decision maker with a measure of their inconsistencies.

The great advantage of the AHP lies in its ability to hand complex real life problems and its ease of use. Compared with five different utility models for determining weights and priorities, AHP was found to produce the most credible results of the models tested (SCHOEMAKER and WAID 1982).

The ability of the AHP to analyze different decision factors without the need for a common numerate, other than the decision maker's assessments, makes it one of the favorable multicriteria decision support tools when dealing with complex problems.

2.2.2.2. Rational for the choice of sustainability assessment by fuzzy evaluation method

"It is fair to say that some clear measures or, at least, indicators of sustainability exist but the effectiveness of policies towards this goal cannot be assessed" (PHILLIS and ANDRIANTIATSAHOLINIAINA 2000). Many attempts have been made to measure sustainability using the economical, the ecological or a combined ecological-economic approach but the results still lack universal acceptance. For the sake of analysis, sustainability has been broken down by researchers into a large number of individual components or indices whose synthesis into one measure appears to be next to impossible. As pointed out in the literature, it is not so much that environmental and socio-economical information is lacking but the fragmentary, often qualitative, and very detailed nature of this information hampers its direct usefulness in policy making (BRINK *et al.* 1991). Not only are there no common units of measurement for the indicators of sustainability but quantitative criteria for certain values are lacking. A systemic method based on a reliable scientific methodology which combines multidimensional components and assesses uncertainty is needed. Such a method should be flexible in the sense that one can add or remove indicators to achieve a better assessment of the system according to context. In reality the border between sustainability and unsustainability is not sharp but rather fuzzy. This means that it is not possible to determine exact reference values for sustainability and a scientific evaluation of uncertainty must always be considered in the procedure of sustainability assessment. "For this reason, the use of natural language and linguistic values based on the fuzzy logic methodology seems more suitable to assess sustainability" (PHILLIS and ANDRIANTIATSAHOLINIAINA 2000).

Fuzzy logic is a problem-solving control system methodology that lends itself to implementation in systems. The concept of Fuzzy logic was conceived by LOTFI ZADEH (1965), a professor at the University of California at Berkley, and presented not as a control methodology, but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership.

Fuzzy logic is a departure from classical two-valued sets and logic, that uses "soft" linguistic (e.g. large, hot, tall) system variables and a continuous range of truth values in the interval [0,1], rather than strict binary (True or False) decisions and assignments (KAEHLER 1998).

The use of the fuzzy logic reasoning is justified by the following two basic features:

1. Fuzzy logic has the ability to deal with complex and polymorphous concepts, which are not amenable to a straightforward quantification and contain ambiguities. In addition, reasoning with such ambiguous concepts may not be clear and obvious but rather fuzzy.
2. Fuzzy logic provides the mathematical tools to handle ambiguous concepts and reasoning, and finally gives concrete answers (crisp as they are called) to problems brought with subjectivity. Sustainability is, indeed, quite subjective. What appears unsustainable for an environmentalist may be sustainable for an economist and the ingredients signifying sustainability may differ for these specialists.

Fuzzy logic is a tool that permits to simulate the dynamics of a system without a detailed mathematical description (LONG and BOEHME 2012c). “Knowledge is represented by “IF-THEN” linguistic rules, which describe the logical evolution of the system according to the linguistic values of its principal characters that we call linguistic variables. Real values are transformed into linguistic values by an operation called fuzzification, and then fuzzy reasoning is applied in the form of “IF-THEN” rules. A final crisp value is obtained by defuzzification, which does the opposite to fuzzification” (PHILLIS and ANDRIANTIATSA-HOLINIAINA 2000).

The sustainability assessment by fuzzy evaluation method is suitable because sustainability is difficult to define or measure, since it is an inherently vague and complex concept. Fuzzy logic, due to its capability to emulate skilled humans and its systematic approach to handling vague situations where traditional mathematics is ineffective, seems to be a natural technical tool to assess sustainability.

The major advantage of fuzzy logic is that it can be used both as compensatory and non-compensatory in a single model at different context, by using inferences through rules extracted from the experts. In this view, PHILLIS and ANDRIANTIATSAHOLINIAINA (2000) studied the usage of fuzzy logic in sustainability assessment. Interestingly though all his inputs were easily quantifiable in nature, he has chosen fuzzy approach to include assumed vagueness and impreciseness in the interpretational measure while representing sustainability.

CORNELISSEN *et al*. (2000) have given the conceptual idea of how to include fuzzy set theory in assessing sustainable development and he has demonstrated a simple one level example of agricultural production sustainability.

Membership function is used as a way to interpret the meaning of the input data and its strength. Hence the nucleus of fuzzy model is its membership functions and it is considered to be the strongest and weakest point of fuzzy set theory (MUNDA *et al.* 1992).

It is no doubt that there is a lot of complexity and fuzziness inherent in the sustainability concept. A possible reduction of this complexity, a pre-condition for management and planning actions, introduces the problem of the descriptors used: indicators and indices (MUNDA *et al.* 1992).

Sustainability is the conceptual aspect of set of processes aimed to deliver desired services over long period of time. Study on sustainability requires an interdisciplinary approach over social, ecological and economic sciences. Measurement of such diverse states of systems is a difficult and complex process that requires dedicated researchers and creative research across many fields. Understanding, designing and managing these systems on a sustainable basis over an entire life cycle is a major challenge facing this generation. Though there is no measuring yardstick by which we can assess sustainability, by emulating human expertise and systematic approach, we can handle imprecise situations through fuzzy logic to give clear picture of reality (JEGANATHAN 2003).

2.3. The role of Vegetables

According to the World Health Report 2002, low fruit and vegetable intake is estimated to cause about 31% of ischemic heart disease and 11% of strokes worldwide (WHO 2002). Overall it is estimated that up to 2.7 million lives could potentially be saved each year if fruit and vegetable consumption was sufficiently increased (FAO/WHO 2004). As evidence, millions of women and children in Sub-Saharan Africa have enough vitamin A in their diets. Vitamin A deficiency causes 250,000 children to blind each year (AVRDC 2003) and raises every child's risk of death from infectious disease, the leading cause of childhood mortality in Africa (FAO/ILSI 1997). Of course, vegetables are vital for healthy diets. Vegetables are not a luxury-they are absolutely essential for human health (AVRDC 2002). Vegetables are rich sources of many essential micronutrients, including vitamins C and K, folate, thiamine, carotenes, several minerals, and dietary fiber (AVRDC 2002). In fact, vegetables are the most sustainable and affordable dietary sources of micronutrients. Malnutrition cannot be solved by simply producing higher quantities of food. The quality of food and specifically, the nutrient contents of the food are just as important. For example, rice, wheat and maize are among the world's most consumed staple foods. However, it would require a person to eat more than five kilogram of either of these staples each day to satisfy their requirements for vitamin A and iron (AVRDC 2002). This is not realistic, on one hand to cultivate this amount and on the other to consume. Consuming a tomato and a few spoonfuls of greens, for example, is a much more reasonable option for satisfying one's daily micronutrient requirements. "Vegetables are vital for our lives" (AVRDC 2004). Healthy diets improve the learning capacity and productivity of workers. In contrast, poor diets lead to poor mental and physical development, poor performance in school, poor productivity in the workplace, and the likelihood of poverty in future generations. All children deserve a healthy start to their lives-anything less is unacceptable. But not enough vegetables are available, especially to poor families. Two billion persons, the vast majority of whom are women and children, do not have adequate access to the micronutrient-rich vegetables they need (KALB and LUMPKIN 2006). More vegetables are required to nourish all persons. Vegetables are vital-they are not a luxury. Vegetables are vital for strong economies. Vegetable production provides jobs-more jobs "vegetables are labor-intensive crops" (JUSTIN *et al.* 2009) compared to cereal production, per ha of production. Vegetable production supports agribusiness and related service industries, thereby creating economic opportunities. Vegetable production diversifies and generates farm income, usually to a greater degree than other agricultural products. Furthermore, vegetable production develops management and leadership skills among farmers. A strong vegetable sector is an "engine for economic growth" (AVRDC 2003).

2.4. Vegetable consumption in selected countries in South East Asia

From 1979 to 2000, the supply of vegetables in Asia increased by 105.3%. However, on average South East Asia people could access only 318.4 grams of vegetables per day (WHO 2003). Table 2.2 shows the estimated levels of fruits and vegetables consumed in certain Southeast and South Asia countries. Consumption of fruits and vegetables is only 50-60% and much lower than those recommended (400 g/day) by WHO for all age groups and all countries. Socio-economic class did not affect the amount of fruits and vegetables consumed in some selected Asia countries.

Table 2.2. Estimated regional intake of fruit and vegetable in selected countries in Asia

Age (yr.)	**Daily per capita consumption (g)**		**Daily per capita consumption (g)**	
	Male	Female	Male	Female
	low child and adult mortality region[a]		high child and adult mortality region[b]	
0-4	108	107	94	95
5-14	198	183	177	170
15-29	245	201	258	224
30-44	243	195	262	229
45-59	258	202	262	227
60-69	248	201	259	229
70-79	244	201	259	228
≥80	225	173	234	205

Source: LOCK *et al.* 2005

[a] Countries: Indonesia, Sri Lanka, Thailand

[b] Countries: Bangladesh, Bhutan, Korea, India, Maldives, Myanmar, Nepal

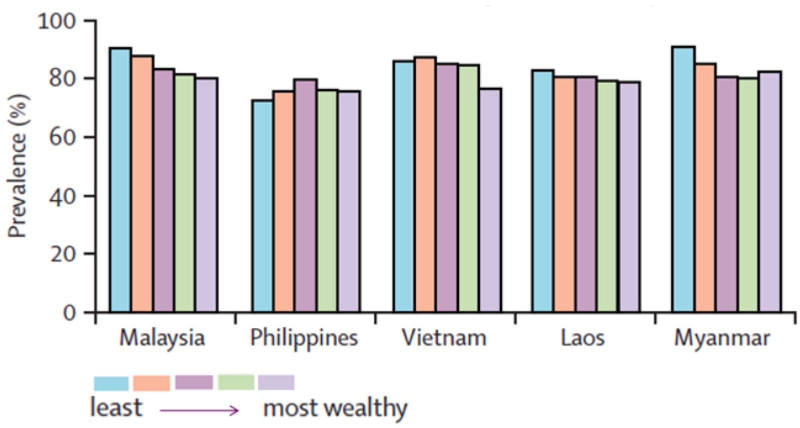

Figure 2.3. Prevalence of insufficient fruit and vegetable consumption in selected countries in South East Asia in 2003 (DANS 2009)

Figure 2.3 show that 80% of people of all economic classes in half of the Asia countries did not consume enough fruits and vegetables. In many developing countries, as well as urban areas, accessibility and affordability may be one main cause for low fruit and vegetable consumption, especially among low and medium income people

2.5. Vegetable production in selected countries in South East Asia

The vegetable production area in some countries in South East Asia increased 17.38% between 2000 and 2010 (from 1,512,052 to 1,774,885 ha), with the annual growth rate is 1.58% per annum (Table 2.3 and Figure 2.3). The vegetable production area increased remarkably in Indonesia with (37.15%), Myanmar (34.25%) and Vietnam (22.21%). Whereas, decreased in Laos, Thailand and Cambodia with 16.62%, 6.43% and 1.89%, respectively (Table 2.2) (FAOSTAT 2011).

The overall vegetable production in the region has increases from 15,125,818 tons in 2000 to 17,519,393 tons in 2010, which represents an annual growth rate of 1.95%. The production increase is due to the expansion of area under vegetable cultivation, and to the overall growth of productivity. The total cultivable land in all selected countries in South East Asia is almost at saturation, but the proportion under vegetable cultivation is increasing (Figure 2.4), which indicates that crop diversification is taking place.

Table 2.3. Harvested area of vegetable in selected countries in South East Asia (ha)

Year	Vietnam	Cambodia	Laos	Thailand	Indonesia	Philippine	Myanmar
2000	452,900	81,236	104,700	137,000	49,216	480,000	207,000
2001	494,500	76,000	111,150	156,356	47,138	490,000	210,000
2002	500,000	73,182	104,965	138,000	47,454	500,000	215,000
2003	510,000	78,675	118,509	141,000	45,351	495,509	220,000
2004	520,000	79,862	107,150	146,435	59,182	450,000	219,586
2005	525,000	77,000	85,710	145,000	55,080	449,272	238,921
2006	536,914	78,747	83,015	114,847	60,970	500,000	267,094
2007	531,257	78,000	84,335	157,531	58,133	550,119	256,046
2008	529,851	77,794	85,000	157,114	58,000	538,493	274,828
2009	524,937	77,073	86,000	155,657	57,462	534,699	272,279
2010	553,500	79,700	87,300	128,185	67,500	580,800	277,900

Source: FAOSTAT 2011 (processed).

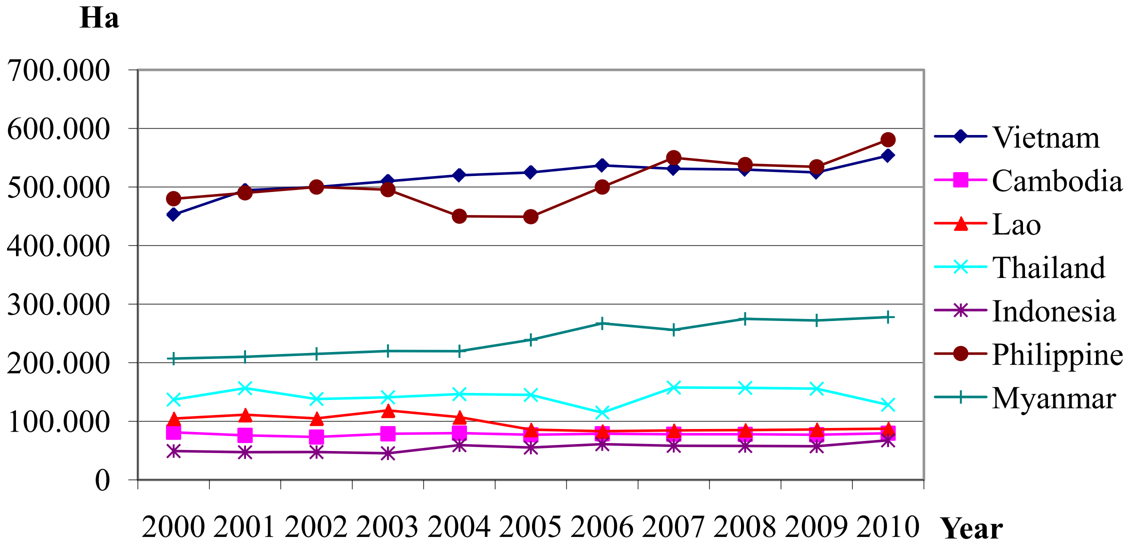

Figure 2.4. Harvested area of vegetable in selected countries in South East Asia (FAOSTAT 2011 - processed)

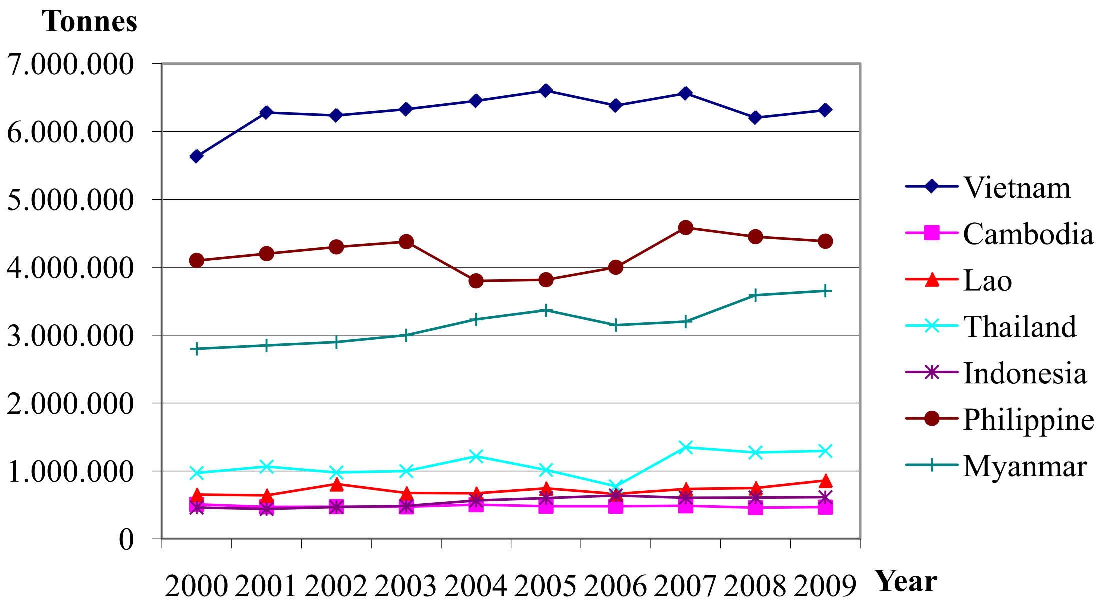

Figure 2.5. The production of vegetable in selected countries in South East Asia (FAOSTAT 2011 - processed)

The average vegetable production (yield/ha/year) is found fluctuating from year to year (Figure 2.5) mainly because of the change in proportion of area under different vegetables, and also because of climate factors. In the longer term, the yield of major vegetable crops has significantly increased, which indicates a growing impact of the dissemination of crop technology. The average vegetable yield ranges from 5.7 T/ha in Cambodia to 14.7 T/ha in Myanmar (FAOSTAT 2011).

A wide range of vegetable crops is grown in selected countries in South East Asia. There are two distinct groups of vegetables grown, the most important groups are “tropicalized” and temperate vegetables (such as tomato, cabbage, cauliflower…) and for which a large number of hybrid varieties are available. The second group is the tropical and the indigenous vegetables (such as eggplant, chili, kang kong, mustard leaf, yard long bean, and many cucurbits).

3. THE ANALYSIS OF THE AGRICULTURAL SITUATION IN VIETNAM AND IN THE STUDY AREA

This chapter focuses on agricultural issue in Vietnam such as land tenure, farming systems, the household involves to agriculture and so on. The next part of this chapter reviews the horticultural sector, including vegetable production, fruit production, flower, ornamental tree production, and the market relates to the horticultural sector in order to understand the interaction between cropping patterns and the market that effect to the famers, policy maker and the sustainability of vegetable production systems in the future. The chapter also reviews the overview of the study area such as agricultural land area, soil characteristics, climate, and vegetable production. Finally, some regulations, decisions and actions were proposed by Vietnamese government and NGO's in order to promote safe vegetable production and sustainable agriculture are reviewed.

3.1. Vietnam and its agriculture

3.1.1. Agriculture sector shares in GDP in Vietnam

Vietnam is a poor, densely populated country with population in 2011 was estimated at 87.61 million people living on 331.15 square kilometers of land (GSO 2011).

Population density of the Red River Delta is the highest in the country at 944 persons/km^2, followed by the Southeast with population density of 631persons/km^2 (GSO 2011).

Thanks to "*Doi moi*" policy, Vietnam economy has achieving continuously high growth rates for the last 20 years. Average GDP growth rate in 1991 to 2010 was 7.4%. The highest recorded growth rate was 9.5% in 1995 (Figure 3.1). Vietnam's real GDP per capita has increased nine times over the past decades. It was 157 USD per capita per years in 1991, 411 USD in 2001 and 1300 USD in 2011 (GSO 2011). It is expected that the GDP per capita per year will reach 3000-3200 USD in 2020 (CMP 2010).

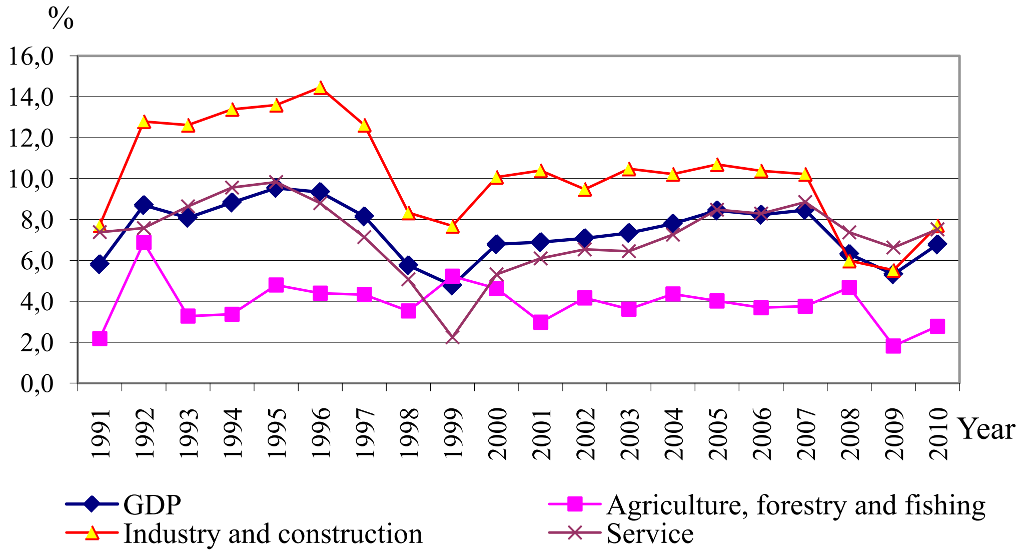

Figure 3.1. Annual growth rate of GDP, agriculture, industry - construction and service from 1991 to 2010 (GSO 2011)

The economic structure has changed considerably (Figure 3.2). The share of agriculture, including forestry and fishery sectors in GDP decrease from 40.5% in 1991 to 20.6% in 2010. Industries and construction sectors increased their share from 23.8% in 1991 to 41.1% in 2010, and the service sector increased its share from 35.7% to 38.3% in the same period. The transition from a centrally planned economy to a market economy caused there changed mainly due to a booming development of trade and services with the highest percentage were 43.7% in the year 1994.

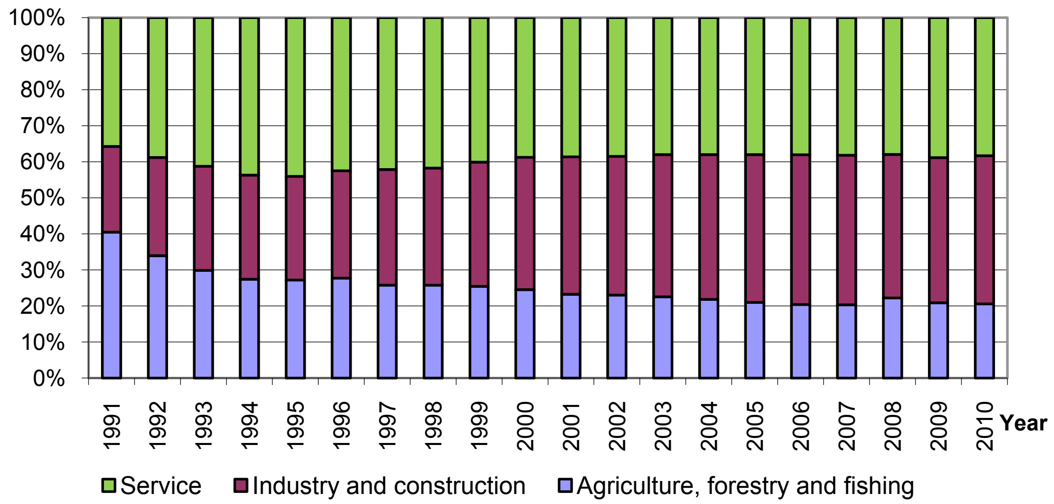

Figure 3.2. Sector shares of GDP from 1991 to 2010 (GSO 2011)

3.1.2. Land tenure and its relates to agriculture in Vietnam

Land tenure has been considered as the important issue of development. Land reform via land allocation and titling has been widely undertaken in transition and developing countries. Land reforms have significantly influenced land tenure, agricultural production, land use, rural livelihoods and environment. Land reform has been considered as one of the key factors that defines patterns and changes in the land use system.

Table 3.1. Historical events relating to agriculture in Vietnam

Year	Historical Timeline
1858	French troops to Vietnam start of colonial period – canal building, introduction of capitalist markets, plantation agriculture and private landlords.
1946	War of independence from France.
1954	Independence from France, country divided into Democratic Republic of Vietnam in North and Republic of Vietnam in South; redistribution of land in the North.
1960s to 1970s	War between North Vietnam (backed by communist allies) and South Vietnam (backed by anti-communist coalition led by USA) – Massive bombing and defoliation campaign destroys agricultural infrastructure, crops and forests, migration to cities.
1975	End of war and reunification of country as Socialist Republic of Vietnam - cutbacks in Soviet and Chinese aid, hostile relations with the West.
1978	Collectivization of agriculture in the South and introduction of green revolution technologies to the collectives in the North.
1979	Invasion of Cambodia and border war with China; economy under great strain, falling agricultural outputs in the North and South of Vietnam.
1981	Instruction 100 - shift from collective agriculture to system of production contracts.
1986	Sixth Party Congress and passage of the *Doi moi* reforms.
1988	Resolution 10 - legalized ownership of livestock and farm implements; land assigned to cooperatives on long-term leases.
1989	Withdrawal of Vietnamese troops from Cambodia; end of Soviet aid and moves to normalize relations with the West.
1993	Land Law - allowance of long-term tradable leases for land.

Source: ADGER *et al.* 2001, LUTTRELL 2001, LUONG 2003 and QUINN-JUDGE 2006

Vietnam was a colony of France for almost 100 years, before achieving independence in 1954 (Table 3.1). At that time the country was divided into two states, the socialist

Democratic Republic of Vietnam in the North and the Republic of Vietnam in the South. Under the rules of the Geneva Accords of 1954, national elections were to be held to vote in a government for a unified Vietnam. However, the South Vietnamese Government, fearing a communist victory, refused to agree on a timetable for the vote and the country was soon plunged into war. A great deal of damage was caused to the social and ecological systems of Vietnam during this period (LUONG 2003). When the war ended in 1975, much of the agricultural land in the South was damaged or abandoned, the population having fled to the main cities. The country was facing food shortages and had the imposing task of rebuilding the national infrastructure

Vietnam is governed by a joint party-government structure. The Communist Party of Vietnam was formed in 1930 and set out to establish a unified force for achieving independence from colonial rule (WESCOTT 2003). The Communist Party of Vietnam ruled North Vietnam following independence from the French in 1954 and has been in charge of the whole country following reunification in 1975. Under this one party system, every citizen over the age of 18 can vote to elect the 500 members to the National Assembly. These members in turn elect the President of the State and the Prime Minister. Prior to 1992 most of the decision-making was carried out by the Communist Party of Vietnam and not by government agencies (WESCOTT 2003). There has been a growing separation between the party and the state following the adoption of a new constitution in 1992, which created a “state structure more appropriate for a mixed economy” (PAINTER 2003). As well as specifying the functions and responsibilities of the government, the judiciary and the National Assembly, the 1992 constitution recognized individual ownership rights and increased the legitimacy of the private sector (WESCOTT 2003). The 1992 constitution “signifies the growing importance of the idea of ‘rule by law’ in the organization and conduct of state affairs” (PAINTER 2003).

Following reunification, the Communist Party of Vietnam attempted to rebuild the country’s food supply through the collectivization of agriculture in the South and the introduction of green revolution technologies to the collectives in the North (CASTELLA *et al.* 2005, QUINN-JUDGE 2006). Under the system of collectivization, which had been operating in the North since the 1960s, land was held in common and people were organized into work teams (QUINN-JUDGE 2006). Village level collectives organized the distribution of external inputs and the outputs of production (ADGER *et al.* 2001). These changes were unpopular in the South and agricultural outputs fell during the late 1970s, a time when the country could least affords it.

The falling agricultural output of the late 1970s led to some initial reforms, but these were mostly applied in a piecemeal fashion (LUONG 2003). In 1981, Instruction 100 allowed for a system of household contracts in agriculture (ADGER *et al.* 2001). Cooperatives could now engage individual households in short-term contracts, with households able to retain any surplus above specific production targets (LUONG 2003). At the Sixth Party Congress in 1986, formal moves towards a market-oriented form of socialism were initiated (LUTTRELL 2001). In 1988, resolution 1 0 legalized ownership of livestock and farm implements, with land assigned to cooperatives on long-term leases. This was followed by the Land Law of 1993 that allowed households to directly apply for long-term tradable leases for land (ADGER *et al.* 2001) (Table 3.1).

3.1.3. The agro - ecological zones of Vietnam

Agro-ecological zone is defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use. Vietnam is a long and narrow country stretched out on a north-south axis, with 3,260 kilometers of coastline. There are 58 provinces in Vietnam and five municipalities in total. These municipalities include Can Tho and Ho Chi Minh City in the Southern part of the country, Da Nang in the centre, and Hai Phong and Hanoi in the North. For administrative purposes the country's 63 provinces and municipalities are subdivided into districts, which in turn are further subdivided into wards and communes. Wards are the more urbanized areas of districts, whereas communes are generally the more rural areas of a district. Wards and communes are further subdivided into hamlets. Government authorities also exist at the provincial, district and ward/commune levels. All three levels of local administration have an elected representative body, the People's Council, and an executive body, the People's Committee (GSO 2011).

The country can be divided into eight agro - ecological zones, each of which contains a number of provinces (Table 3.2 and Figure 3.3). The North East and the North West are sparsely populated mountainous regions bordering Laos and China. The Red River Delta is the country's most densely populated region and contains the capital city of Hanoi. This region is important agriculturally and produces a small surplus of rice, enough to feed the capital city and to cover part of the rice deficit in the North East and North West regions.

Table 3.2. Major agro - ecological zones and the agricultural land in whole country and regions in 2009

	Total natural land area (1000 ha)	Total natural land area (%)	Agricultural production land area (1000 ha)	Agri. production land compared with the total natural land area (%)
Whole country	**33,105.10**	**100**	**9,598.80**	**28.99**
North West	3744.40	11.31	501.00	1.51
North East	5,789.30	17.49	925.40	2.80
Red river delta	2,106.30	6.36	794.70	2.40
North Central Coast	5,152.50	15.56	819.80	2.48
South Central Coast	4,436.10	13.40	946.10	2.86
Central Highlands	5,464.10	16.51	1,667.50	5.04
South East	2,360.50	7.13	1,393.60	4.21
Mekong river delta	4,051.90	12.24	2,550.70	7.70

Sources: GOS 2010

In the table 3.2, there was totally 9,598.80 thousand ha of agricultural land, accounting for 28.99% of the total natural land area of the country. The agricultural land is allocated in the 8 zones with the highest percentage is the Mekong river delta (7.77%), and then the Central Highlands with 5.04%. The lowest percentage is the North West (1.51%) (GOS 2010). The North East, the Red river delta, the North Central Coast, the South Central Coast, the Central Highlands, and the South East with its percentage are 2.80, 2.40, 2.48, 2.86, 5.04, and 4.21, respectively (GOS 2010).

The North Central and South Central Coasts of Vietnam are rice deficit areas and have population densities slightly below the national average. The Central Highlands are mountainous and sparsely populated, bordering Cambodia. The South East region contains the country's largest urban centre, Ho Chi Minh City, and is the third most important agricultural region in the country. The Mekong River Delta in the far south of Vietnam has the second highest population density in the country and is the main agricultural region in terms of the value of output. All of the rice that is exported from Vietnam is grown in the Mekong Delta (GSO 2011).

Figure 3.3. The main agro - ecological zones of Vietnam (DSMV 2009)

3.1.4. Agricultural land area in Vietnam

The agricultural land area has had significant changes from 2001 to 2009 (Table 3.3). The agricultural land area was increased by 18.39% (3,902.45 thousand ha) in 2009, in comparison with 2001. The change for each type of land was different. The agricultural land has been moved to other land use purposes, e.g. residential land, land for business premises, land for public works. The total agricultural production land in 2009 was 9,598.80 thousand ha, increased by 719.74 thousand ha (8.11%) compared to the year 2001, mostly from the unused land.

Table 3.3. Change of agricultural land in Vietnam

Unit: thousand ha

		2001	2009	Change(2001-2009)	
				Quantity	Per. (%)
Total agricutural land		21,224.85	25,127.30	3,902.45	18.39
Agricutural production land		8,879.06	9,598.80	719.74	8.11
+ Annual crop land		6,064.34	6,282.50	218.16	3.60
Of which:	Paddy land	4,337.75	4,089.10	-248.65	-5.73
	Vegetable	450.00	650.00	200.00	44.44
+ Perennial crop land		2,814.72	3,316.30	501.58	17.82
Forest land		11,822.99	14,757.80	2,934.81	24.82
Land for aquaculture		503.47	738.40	234.93	46.66

(Sources: GOS 2007, GOS 2010)

The area for annual crops was increased by 218.16 thousand ha, mostly from reclaimed land for maize or cassava cultivation, etc. On the contrary, the paddy land was decreased 248.16 thousand ha (-5.73%) that means reduced by 31 thousand ha per year on the average. The land for vegetables in 2009 was increased by 200 thousand ha, compared with 2001, due to the move from paddy cultivation land (GOS 2007, GOS 2010).

The land for perennial crops was increased by 501.58 thousand ha, compared with 2001, mostly due to the move from unused hilly land and reclaimed miscellaneous garden land. The forestry land was increased by 2, 934.81 thousand ha (24.82%) compared with 2001, mostly due to the move of unused hilly land to reforestation (GOS 2007, GOS 2010).

The aquaculture land was increased 234.93 thousand ha, due to shifting from the inefficient one-crop wet paddy cultivation land. The increase on the aquaculture land was mostly concentrated in the Mekong river delta, the Red river delta and the North Central Coast (GOS 2007, GOS 2010).

3.1.5. Farming systems in Vietnam

According to GOS 2011a, there are 20,065 farms in the whole country, of which Mekong Delta had 6,308 farms, accounting for 31.4% of farms, the South East region had 5,389 farms accounted for 26.9% in the country, and the Red River Delta stood in the third rand with 3,506 farms accounted for 17,50% (Table 3.4).

There were 8,642 crop farms accounted for 43% of the total farms in the country and distributed mainly in South East, Mekong Delta and Central Highlands regions (7,809 farms account for 90.4% crop farms nationwide).

Table 3.4. Number of farms in Vietnam in July 2011

	Total farms	Of which				
		Crop farm	Livestock farm	Forest farm	Aquaculture farm	Mix farm
Whole country	20,065	8,642	6,202	51	4,433	737
Red river delta	3,506	39	2,396	3	923	145
Midland and mountainous in the North	587	38	506	6	21	16
Central Coast	1,747	756	512	38	258	183
Central Highlands	2,528	2,138	366	0	9	15
South East	5,389	3,434	1,844	4	55	52
Mekong river delta	6,308	2,237	578	0	3,167	326

Sources: GOS 2011a

The livestock farms were 6,202 and accounted for 30.9% of total farms in the country and distributed mainly in Mekong Delta and Red River Delta with 4,240 livestock farms (68.3% of total livestock farms in the country). There were 4,433 aquaculture farms accounted for 22.1% and concentrated in Mekong Delta and Red River Delta with 4,090 farms account for 92.3% of total aquaculture farms in the country. The mix farms were 737 farms, accounted for 3.7% and 51 forest farms accounting for 0.3% of total farm in the whole country (Figure 3.4).

At the time of 01/7/2011, agricultural land, forest and water area by aquaculture farms is using is 157.6 thousand ha, an average of 7.9 ha/farm. The total land for perennial crops accounted for the largest share with 78 thousand ha (49.5%), annual crop land 36.7 thousand ha (23.3%), aquaculture area 34.2 thousand ha (21.7%), 8.7 thousand ha of forest land (5.5%). Land area of agriculture, forestry and fishery an average farm is highest in the Southeast region 10.9 ha, 8.8 ha Highlands, North Central and Central Coast 8.7 ha, Delta Mekong 7.3 ha, Northern mountainous 4.9 ha and Red River Delta 3.6 ha. Land area of agriculture, forestry and fisheries in 2011 the average farm in the country and the region higher than the previous year, mainly due to changes in criteria of farms (GOS 2011a).

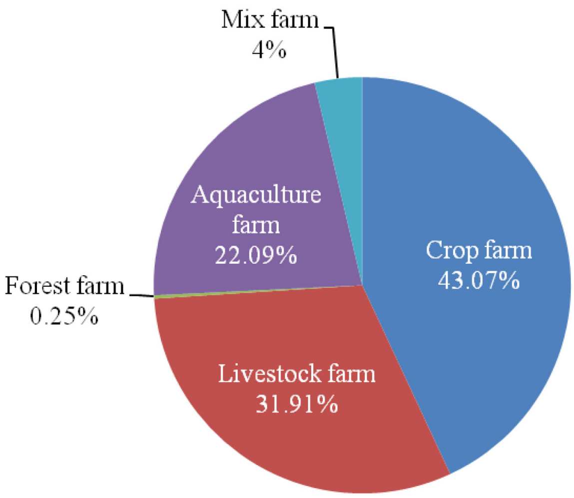

Figure 3.4. Type of farm and its proportion in Vietnam in 2011 (GOS 2011a)

3.1.6. The households involved to agriculture in Vietnam

Until the first of July 2011, there were 10.36 million agricultural, forestry and aquatic households, reduced 106 thousand households (-1.0%) to compare with the year 2006 - this is a positive trend in its operations production in our country. However, the trend increasing or decreasing was different and uneven across regions. The Central Highlands the largest increase with 115 thousand households (+15.3%) compared with 2006, Midland and mountainous in the North with over 93 thousand households (+5.1%), the Mekong river Delta increased by 0.2%. The Red River Delta decreased with 255 thousand households (-11.4%), South East fell down by 2.3%, and Central Coast decreased 1.8%. Within the group of agricultural, forestry and fisheries, the agricultural households have diminished while forestry and fisheries households have increased correspondingly (Table 3.5) (GOS 2007, GOS 2011).

Table 3.5. Number of households involved to agriculture in Vietnam

	Total		Agriculture		Forest		Aquaculture	
	2006	2011	2006	2011	2006	2011	2006	2011
Whole country	10,462,367	10,356,357	9,740,160	9,583,846	34,223	65,229	687,984	716,282
Midland and mountainous in the North	1,813,564	1,906,896	1,799,031	1,886,139	8,161	11,635	6,372	9,122
Red river delta	2,248,026	1,992,870	2,169,691	1,911,897	2,956	3,960	75,379	77,013
Central Coast	2,669,079	2,620,486	2,438,606	2,366,285	13,339	32,332	217,134	221,869
Central Highlands	751,647	866,623	749,966	864,746	995	1,368	686	509
South East	616,638	602,520	588,512	573,497	2,027	2,236	26,099	26,787
Mekong river delta	2,363,413	2,366,962	1,994,354	1,981,282	6,745	4,698	362,314	380,982

(Sources: GOS 2007, GOS 2011)

Agricultural households: The country has 9.58 million households in 2011 decreased 15.6 thousand households (-1.6%) compared to 2006. Four out of six social - economic regions has declined trend in agricultural households. Number of households has decreased at the highest in the Red River Delta, decreased nearly 260 thousand households (-11.9%), Central Coast and South East and Mekong river delta fell down 3%, 2.6%, and 0.7%, respectively. The two regions have increased the number of agricultural households such as in the Central Highlands with 115 thousand households (+15.3%), Midland and mountainous in the North declined by 4.8% (GOS 2007, GOS 2011).

Forestry households: The country has 56.2 thousand households, increased 31 thousand households (+99.6%) to compare with 2001, an annual increase of 11.3%. The number of households increased highest in Central Coast region (+142.4%), and then Midland and mountainous in the North (+42.6%), Central Highlands (37.5%), Red river delta (34%) and South East (10.31%). Number of households has decreased in the Mekong River Delta, decreased over two thousand households (-30.4%) (GOS 2007, GOS 2011).

Fishery households: With the rapid development of aquaculture production in recent years, the number of fishery households also increased rapidly in most of the regions. By 2011, the country had 71.6 thousand households aquatic products, increased 2.9 thousand households (+4.1%) compared to 2006, including the Red River Delta increased by 2.75 thousand households (+43.2%). But decrease in the South East region with 0.18 thousand households (-25.8%) (GOS 2007, GOS 2011).

3.1.7. Structure of rural households involved to agriculture in Vietnam

Number of rural households nationwide in July 2011 at 15.35 million households increased 1.58 million households (+11.5%) in comparison to the year 2006. The fastest-growing is visible in the South East region (+26.74%) and Central Highland (+17.5%). Growth rate of rural households period 2006 - 2011 higher than the period 2001 - 2006 (period from 2001 to 2006 increased by 0.7 million (+5.4%) caused due to increasing demographic, divided households (the size of households in rural areas decreased markedly) (GSO 2011a).

Structure of agricultural, forestry and fisheries household in the whole country (Figure 3.5) has a rapid decreased from 9.52 million households in 2006 to 9.25 million households in 2011 (-2.7%). Meanwhile, the number and proportion of industrial, construction and service households increased 47.2% from 5.09 million households in 2006 to 6.72 million households in 2011 (GSO 2011a).

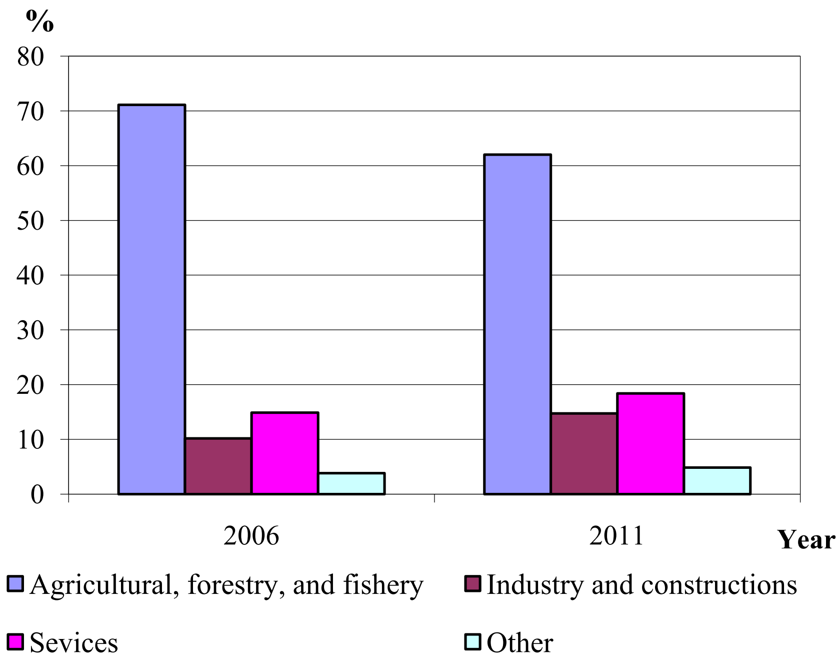

Figure 3.5. The structure of rural households in Vietnam in 2006 and 2011 (GSO 2007 and GSO 2011a)

In comparison to the year 2006, the proportion of agricultural, forestry and fisheries households in rural areas decreased from 71.1% to 62.0%. The proportion of industry and construction households rose from 10.18% to 14.73%, the proportion of services households from 14.9% to 18.4%, respectively (GSO 2011a).

It is noteworthy that in 2011, there were 11/63 provinces in the whole country account for 17.5% has the proportion of industrial, construction and services over 40% of rural households (in 2006 only 5/63 provinces). The highest percentage of rural households working on industrial, construction and services belong to the South - East region with 58.1%, the second is the Red River Delta region with 44.5%, and then the Mekong river Delta with 32.2% percentage of rural households working on industrial, construction and services (GSO 2011a).

3.2. Horticultural sector in Vietnam

Vietnam is an agricultural country where 69.43% of population (60.83 million persons) is involved in agricultural production (GSO 2011a). Agricultural production in Vietnam is almost at household scale. Local farmers have established cultivated custom and accumulated production experiences, especially flower, vegetable and fruit cultivation, which plays an important role in horticulture in Vietnam. There are highly valuable and multi-labor required in vegetable, fruit and flower cultivation.

3.2.1. Vegetable production

Most of the rural households in Vietnam grew vegetables. In 2010, the country has 22.44 million households (GSO 2009) with 10.26 million households involved to agriculture of which 9.6 million households engaged to crop production (GSO 2011a).

Cultivation of fruit and vegetables by poor farmers was higher (70%) than the richest category of farmer (59%), perhaps due to poor households having greater ability to supply the labor needed for vegetables. Most productions were sold (63%), with the poorest households selling at least half, and more farmers from the south (91% for fruit and vegetables in Mekong Delta) than the north (46% for fruit and vegetables in northern uplands) selling a portion of production. Marketed-share ranged from 91% from Mekong Delta farms (86% in southeast farms), to 50% from northern uplands farms (54% from Red River Delta). Commercialization of production was increased (HUNG *et al.* 2004).

In the Red River Delta, average farm size is around 0.25 ha. This land is comprised of on average 8-10 noncontiguous plots of land, some of which are only 200 -500 m^2 in size (HUNG *et al.* 2004). It should be noted that a larger cooperative unit of farm (trang trai) is also recognized. In 2011, there were more than 20065 agricultural, forestry and aquatic organizations registered as - farms (trang trai) in Vietnam, and with an average size for annual crop farms of 4.25 ha (GSO 2011a).

In the 1990's, the area planted with vegetables and beans grew at 5% per year-twice the growth rate for food crops, but lower than the growth rate for industrial crops, and accounted for 5% of total cropping area (MARD 2010).

Between 1991-2009, annual vegetable production has increased remarkably 26.1% from 138.5 thousand ha to 650 thousand ha (Figure 3.6). In 2009, vegetable production rose 6.4% over 2005 productions, although 100,000 ha of vegetables was destroyed by three typhoons that affected the central, southeast, and Mekong regions (MARD 2010), with the production from 3.21 to 9.39 million tones and average yields reaching 14.7 t/ha. Vegetable average yield in the whole country has significantly increased 16.24% annual in the same period. Some intensive vegetable regions in Lamdong - Central highland has created an evident increase of yield. The vegetable yield in the Red River Delta and Central Coast have stably increased year by years.

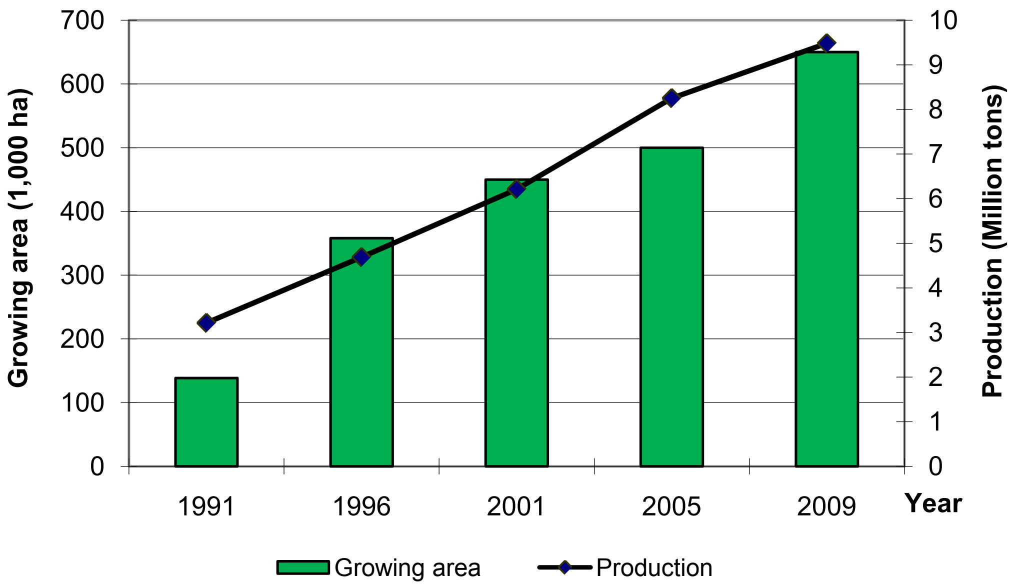

Figure 3.6. Area and production of vegetables in Vietnam, 1991-2009 (AGROVIET 2006 and MARD 2010)

For the past 20 years, there have been increasing of not only yield, productivity, abundant species, but also higher rate of superior and safe vegetables that contribute to ensure benefit triangle for producers, traders and consumers and to establish some specialized production areas of some main vegetable kinds as follows:

- Cabbage growing areas: Da Lat, Hanoi, Hai Phong, Hai Duong, Hung Yen
- Tomato growing areas: Da Lat, Hanoi, Hai phong, Hung yen
- Cucumber growing areas: Da Lat, Hanoi, Hung Yen, Ha Nam, Nam Dinh
- Chili growing areas: Quang Binh, Quang Tri, Thua Thien Hue, Quang Nam, Da Nang, Thai Binh, Bac Ninh, Bac Giang

3.2.2. Fruit production

In recent years, fruit production has strongly developed, especially the results from the programme on development of fruit, vegetable and flower in the period of 1999-2010. The area of the fruit increased rapidly in recent years, reaching 766.9 thousand ha in 2005 (compared with additional thousand ha in 1999, growth averaged 8.5% / year), for output of 6.5 million tonnes (of which the largest banana producing about 1.4 million tons, followed by citrus: 800 thousand tons, labels: 590 thousand tons). Cuu Long River Delta area of the largest fruit (262.1 thousand ha), production reached 2.93 million tons (35.1% in area and 46.1% in volume). Litchi, longan, and rambutan are the most developed, making up 26% of the total fruit tree area; banana alone makes up about 19% (JOHNSON *et al.* 2008).

Thanks to a diversified ecology Viet Nam has more than 30 kinds of fruit trees, belonging to three groups as follows:

- Tropical fruit trees such as banana, pineapple, mango, etc.
- Semi-tropical fruit trees: orange, mandarin, litchi, longan, etc.
- Temperate fruit trees: plum, pear, etc.

All over the country, initially formed fruit growing areas of highly concentrated, for large quantity of goods; some focus areas of fruit trees typically as follows (JOHNSON et al. 2008):

Fabrics anthems: the fabric set is the largest center of Bac Giang (mostly in Luc Ngan, Luc Nam and Lang Giang), an area of 35.1 thousand ha, production reached 120.1 thousand tons. This is followed by Hai Duong (concentrated in two districts of Thanh Ha and Chi Linh) with an area of 14 thousand ha, 36.4 thousand tons of output.

Orange: the growing concentrated in the Mekong Delta, an area of 28.7 thousand ha, yielding over 200 thousand tons. Local production is the largest province of Vinh Long in

2005 for the production of over 47 thousand tons. Next is the Ben Tre province (45 thousand tons) and Tien Giang (42 thousand tons). On the northern mountainous Midland, orange trees are planted along quite concentrated in Ha Giang province. However, New production was nearly 20 thousand tons.

Rambutan: Local area rambutan largest concentration Dong Nai province (11.4 thousand ha), followed by the Ben Tre (4.2 thousand ha).

Dragon fruit: the growing concentrated mainly in Binh Thuan (about 5 thousand ha area, the output nearly 90 thousand tons, accounting for 70% area and 78.6% in volume dragon country). Next is the Tien Giang, have 2 thousand ha. Dragon fruit trees with the largest turnover in comparison with other fruits.

Grapefruit: Vietnam has many delicious pomelo, consumers rated as roi pomelo, Da Xanh, Phuc Trach, Thanh Tra, Dien, Doan Hung ... However, only “Roi” pomelo is meant to yield large quantities of goods. The total area of “Roi” pomelo is 9.2 thousand ha, the main distribution in Vinh Long province (an area of 4.5 thousand ha for the production of 31.3 thousand tons, accounting for 48.6% of area and 54.3% in “Roi” pomelo of the country), which focus on Binh Minh: 3.4 thousand ha with an output of nearly 30 thousand tons. Next is the Hau Giang (1.3 thousand ha).

Mango: also the trees density planting large areas of Vietnam. There are many varieties of mango being grown in the country's high-quality seeds and planting practice high as Hoa Loc mango varieties. Hoa Loc mango is distributed along the by Tien Giang with an area of 4.4 thousand ha with an output of 22.6 thousand tons. The area of Hoa Loc mango concentrate mainly in Tien Giang province (the area of 1.6 thousand ha, 10.1 thousand output tons), followed by Dong Thap province (873 ha, yield 4.3 tons).

Mangosteen: is the left tropical plants are very delicious and nutritious. Mangosteen grow mainly in the Mekong Delta with a total area of 4.9 thousand ha, yields about 4.5 tons. Ben Tre province is an area set high capacity: 4.2 thousand ha (accounting for 76.8% of the country). The cement dead-end product is very price in the market but the expansion of the plant area is currently impeded by the time the ants basic term (5-6 years), the large trees, take up valuable space land and land suitable for coloring in the islets.

Pineapple: This is one of three leading fruit crops are encouraged to invest in the development recently in service exports. The main varieties used of the same Queen and Cayenne of which is similar Cayenne yield highly suitable for processing (fruit juice concentrates, natural pineapple juice ...). The Local area focus mainly pineapple Tien

Giang (3.7 thousand ha), Kien Giang (3.3 thousand ha); Nghe An (3.1 thousand ha), Ninh Binh (3.0 thousand ha) and Quang Nam (2.7 thousand ha).

In addition, there are some other fruits can also be exported fresh: Durian rice yellow floaters, breast milk forge, press down yellow flesh ... However, the area and production is still modest, not sufficient for domestic consumption and domestic price even higher export prices.

On the contrary categories plants a competitive advantage, Ministry of Agriculture and Rural Development identified 11 types of fruit plants a competitive advantage, including dragon, breast milk, Mangosteen, Plants citrus (grapefruit, orange), mango, durian, pineapple, litchi, longan, coconut and papaya.

According to the planning of the Prime Minister for restructuring of agriculture, forestry and fishery with fruit-oriented to grow new varieties of crops, and enlarge the area to about 1.3 million ha in 2020 mainly in the midland and mountainous area in the North, in the Mekong River Delta, in the South East, and in the Red River Delta.

3.2.3. Flower and ornamental tree production

Vietnam has an advantage in climatic diversification where flowers can be grown year-round. However, flower and ornamental tree area in Vietnam are small and disperse and just only 0.02% of total land area. The area of flower plants are 12,054 ha in 2008 (Table 3.6). The average value was 70 to 130 million VND per ha (HANG 2010).

In the north, Hanoi is considered the largest flowers area. Tu Liem District with an area of 500 ha, mainly cultivated as daisy, roses, lilies... Other peri-urban districts in Hanoi and some other provinces such as Vinh Phuc, Hung Yen, Thai Binh ... has planned for cultivation of flower areas to serve local needs.

Some provinces in Central Coast region also have been developing the commercial cut flowers production but primarily serve local needs, with limited of flower species. The southern provinces, especially Ho Chi Minh City, including the districts of Hoc Mon, Binh Chanh, Go Vap, Thu Duc, Cu Chi ... and some provinces in the Mekong River Delta such as Tien Giang, Dong Thap provinces are the source of flowers. However, the area and the production of traditional cut flowers is very limited and not very high quality. Dalat - Lamdong is famous for flower production in Vietnam where good climatic conditions, land suitable for the development of flowers with high economic value Da Lat - Lam Dong is considered as the center of cut flowers with the highest production and the largest cut flower area and has been capable of producing year around (HANG 2010).

Florist's area of Lam Dong province in 2008 reached to 1,728 ha, mainly in Da Lat city with output of about 640 million flower stems (HANG 2010). Da Lat tends to apply of new technologies that can help farmers to solve the problems of breeding, disease prevention, and to build a brand for Da Lat flowers.

Table 3.6. The flower area and its values in Vietnam

Regions	Year					
	2006		2007		2008	
	Area (ha)	Value (million VND)	Area (ha)	Value (million VND)	Area (ha)	Value (million VND)
Whole country	8.512	320.284,100	9.430	482.606,900	12.054	572.738,000
North West	5.196	184.975,579	5.721	196.489,100	7.119	261.414,000
North East	107	5.576,630	168	17.686,000	506	34.757,000
Red river delta	32	351,000	33	402,500	10	18,000
North Central Coast	130	2.052,300	139	1.833,700	174	872,000
South Central Coast	558	39.652,282	564	34.528,159	431	16.982,000
Central Highlands	1.345	50.168,200	1.583	193.850,200	1.801	204.775,000
South East	1.016	32.790,134	1.013	33.033,470	1.581	38.846,000
Mekong river delta	128	4.717,972	209	4776,806	432	15.074,000

Sources: HANG 2010

The flowers are grown in Da Lat - Lam Dong very diverse, covering many different categories: Daisy (*Chrysanthemum sp*) with over 40 cultivars from different regions: Indonesia, Netherlands, Japan, and Korea ... Carnation (*Dianthus caryophyllus*) diversity with 14 cultivars. Roses (*Rosa sp*) with over 15 cultivars, originating from Italy, the Netherlands, the United States... Dalat also produced a number of different types of flowers such as gladiolus (*Gladious communis*), lily (Lilium longiphorum), and gloxinia (S*inningia speciosa*) (HANG 2010).

The development of flowers in Da Lat has been increasing spontaneously. The propagation by tissue culture methods are becoming more prevalent, but no control, no assessment of the quality that may has pathogens (HANG 2010).

3.2.4. Domestic and foreign markets for vegetables, fruits, and flowers of Vietnam

3.2.4.1. Domestic market

Vegetable products: In addition to vegetable separately produced and consumed by local people, vegetable amount produced in peri-urban areas of big cities and specialized production areas are transported to people in big cities, towns, industrial zones to meet very big demand.

In recent years, vegetable quantity is increasing to sufficiently meet domestic demand. For example, in 2003, vegetable consumption per capita per year was 102 kg that was higher than proposed objective of 80 kg/capita/year in 2005. If this space is used for export, it will be a significant number. However, from May to September when vegetables are insufficient, vegetables imported from China are consumed in big cities, towns, industrial zones.... But the problem is that custom office cannot control all of these vegetables that mean these vegetables are not legally imported to Vietnam through border gates, and then origin of these products does not know (JOHNSON *et al.* 2008).

Vegetable consumption in Vietnam

The total national nutrition survey in 2010 was implemented from September in 2009 through 2010 by National Nutrition Institute and the General Department of Statistics carried out on 7600 households living in all regions in the country in order to assess the effectiveness of nutrition programs implemented in 10 years and gather information to build a national strategy on nutrition for the coming period. The results of the survey showed that in the last decades, the daily diet of Vietnamese people was monotonous diet with mainly of rice, vegetables and less meat. Nowadays, the monotonous diet model is still available in some poor families in both rural and urban, but the large proportion of inhabitants in cities, rural areas with affluent income have been increasing, so the physical structure the meals have been changing significantly.

The consumption of meat increased 60% from 50 grams/person per day in 2000 to 84 grams/person per day and higher than the level recommended, while the consumption fish and other aquatic products, especially vegetables were lower than the recommended level (LAN ANH 2011). People ate more and more meat, and eggs than before, meanwhile the amount of vegetable consumption has been reducing 11.12% from 1985 to 2010 (Table 3.7).

Table 3.7. Changes in the diet of Vietnamese people (g/person per day)

Year / Foods	2000	2010
Meats	51	84
Fish	46	60
Milk and eggs	10	30
Oil	25	38
Vegetable	214*	190

Note: * data in 1985 (LAN ANH 2011)

Fruit products: Similarly, fruit productivity and its domestic demand are increasing year by year. Fruits are domestically consumed as fresh, drying, jam, syrup (apricot, lemon,...), and according to surveyed results by CIRAD and Social Institute in 2002 showed that 25% of questioned people confirmed that fruits are always available for their meals. Especially, in Vietnam, on 1st and 15th of lunar month, lunar new year festival, mid-autumn day,... are much consumed. However, fruits should be imported from China in off seasons because fruit harvesting is concentrated in specific duration, while storage technologies have not been able to easily apply in large scale (JOHNSON *et al.* 2008).

Flower and ornamental tree: Although Vietnam is a developing country, demand of flower and ornamental tree is higher and higher due to improved living standard, especially in big cities. Flowers, which are popularly use based on daily fresh flower consumption, are rose, chrysanthemum, gladiolus, lily...

3.2.4.2. Export of vegetables, fruits and flowers

In fact, export of fruits and vegetables are difficult to separate. Therefore, this item will reflect both in common.

Period before 1990: Export markets of fruits and vegetables of Vietnam were Soviet Union and East European countries. Domestic businesses were mainly concentrating on production organization, product gathering and delivery, but they did not worry about seeking export markets. Moreover, those export markets required quality at medium level. According to Cooperative programme on production and export of vegetables and fruits to Soviet Union, this trading sector was supported lots of important materials serving production and export activities (JOHNSON *et al.* 2008).

Period of 1991 - present: After 1990, Soviet union and East European markets were changed, thus, vegetable and fruit export of Vietnam sharply declined from 1991-1994 (from 52.3 million USD to 20.8 million USD). It is the period when processing businesses had the most difficulties because export agencies were not supported and facilitated as before. They had to look for export markets, maintain relationship with customers in new type, then vegetable and fruit export turnover had gradually recovered and increased in recent years (1999, 2000), reach high peak in 2001, and then decreased (JOHNSON *et al.* 2008).

In 2009, there were 82 kinds of fresh, dry, and processed fruit and vegetable exported to the EU market. Of which, there were five items gaining highest turnovers including pineapple, cucumber, mushrooms, dragon fruit and litchi. Export turnover of those reached 19.6 million USD, accounting for 61.5% of the total export turnover of fruit and vegetable to the EU (RAUHOAQUAVIETNAM 2010).

In 2009, Pineapple was still found with the highest turnover of 12.3 million USD, increased 41.8% compared with 2008. Secondly was cucumber with turnover reached 6.1 million, grew up 27.2% compared with 2008. Dragon fruit exports reached 4.3 million, up 8.65% compared with 2008 (RAUHOAQUAVIETNAM 2010).

Mushroom export turnover has increased significantly as compared with 2008, passing dragon fruit and taking the third position among export items of fruit and vegetable that achieved the highest export turnover in 2009 (RAUHOAQUAVIETNAM 2010).

In addition to the high - valued export items found above, there were quite a lot of new items exported in the past year, such as guava, shallot, aloe, chayote, and bamboo shoot.

In 2011, fruit export turnover is around 600 million USD, an increase of 150 million USD compared to that in 2010. At present, Vietnamese fruits and vegetables are being exported to 50 countries and territories around the world with core markets being China, Japan, Indonesia, the Netherlands and Russia (Figure 3.7) (RAUHOAQUAVIETNAM 2010).

Vietnam cultivates dragon fruit on 1,300 ha in the central province of Binh Thuan, has 9 packaging plants and two radiation factories. The country has seen an increase of dragon fruit exports to the US from 100 tons in 2009 to 1,300 tons in 2011 (RAUHOAQUAVIETNAM 2010).

Rambutan export volumes to the US have risen from only 2 containers to 20 containers per week, as the unseasonal fruit is not competitive with the Thai and Mexican variety.

As mentioned above, flower demands in Vietnam have increased in recent years that promote flower and ornamental tree development. Apart from meeting domestic demand, flowers are also use for export. According to surveyed results by the Research Institute of Fruits and Vegetables flower export value was 3.6 billion VND, 5.2 billion VND and 7 billion VND in 1999, 2000, 2001, respectively (1 USD= 15,500 VND in 2000). Main exported flower species is chrysanthemum and rose but at low level compared with its potential due to high quantity but low quality, not having good varieties to prolong harvesting season to regularly supply to market (JOHNSON *et al.* 2008).

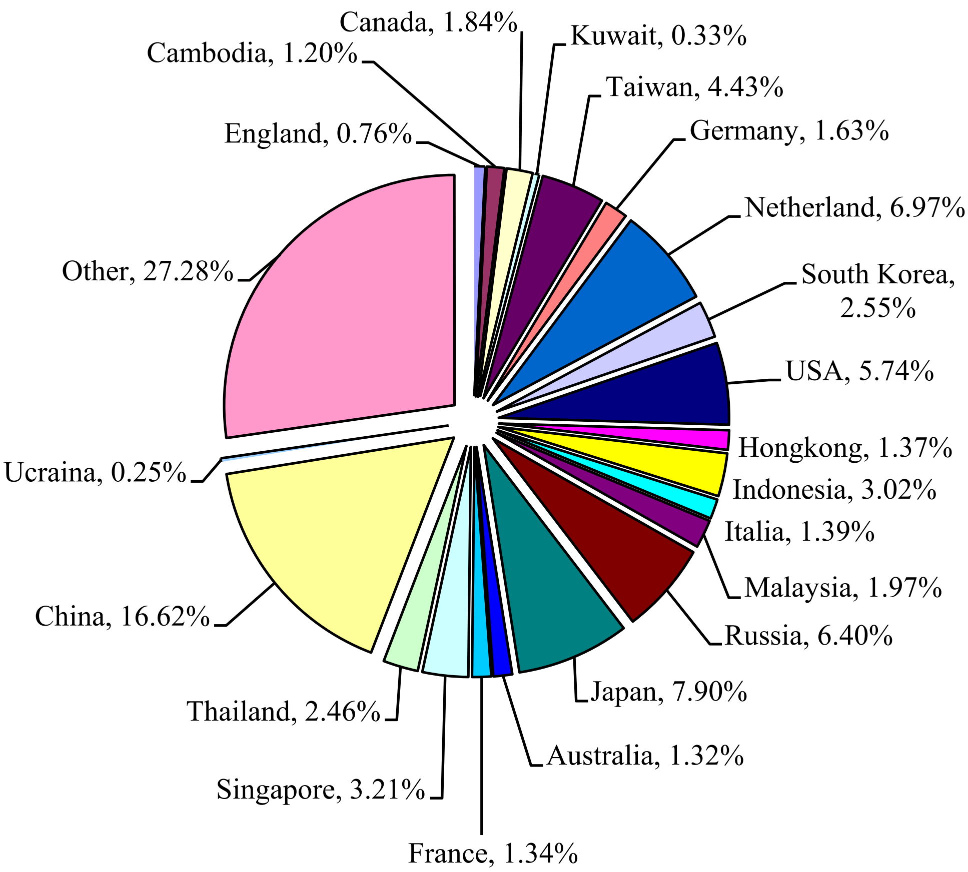

Figure 3.7. The main export market of vegetables, fruits and flowers of Vietnam in 2010 (DIENDANCAPHE 2010)

In 2009, the Netherlands was still the market that generated the highest turnover of more than 16 million USD, increased 27% over the same period in 2008. Although most of Vietnam's export markets of vegetable and fruit were lower in turnover, the Netherlands was highlighted as with a stable growth since the beginning of the year.

Notably, export turnover of vegetable and fruit to Manta reached a high of 10.6 thousand USD, increased by 14.7 times (VIETNAMNEWS 2011). Though export turnover to this market did not make much, that efforts by Vietnamese enterprises should be awarded.

There were also export markets that saw reduction in turnover besides, such as Finland, Austria, Sweden, with respective turnovers of 62 thousand USD, 91.7 thousand USD and 408.2 thousand USD, declined by 55.1%, 47.7% and 58.8% (VIETNAMNEWS 2011).

In 2009, the export volume of fruit and vegetable to EU reached 49.6 million USD, increased by 9.4% compared with 2008. A wide variety of fruit and vegetable have been promoted and exported to that market, such as dragon fruit, mango, sapodilla plum, and coconut. Remarkably, there were quite a few new species of fruit and vegetable exported to EU in 2009 like longan, spondias cytherea, kumquat, bamboo shoot, basil, and coriander (VIETNAMNEWS 2011).

3.3. Overview of the Red River Delta, Vietnam

The Red River Delta (Figure 3.8) is one of the eight ecological regions in Vietnam. The area of this region is 21049.20 square kilometers of which 749,200.00 ha (59%) are agricultural land. The Red River Delta had a population of 19.6548 million with a population density of 934 persons per km2; this is the most densely populated region of Vietnam. It consists of the following eight provinces: Hanoi, Hai Phong, Hai Duong, Hung Yen, Ha Nam, Nam Dinh, Thai Binh, and Ninh Binh. The region contributed approximately 19% of the total national agricultural gross output which is ranked second after the Mekong River Delta (GSO 2009).

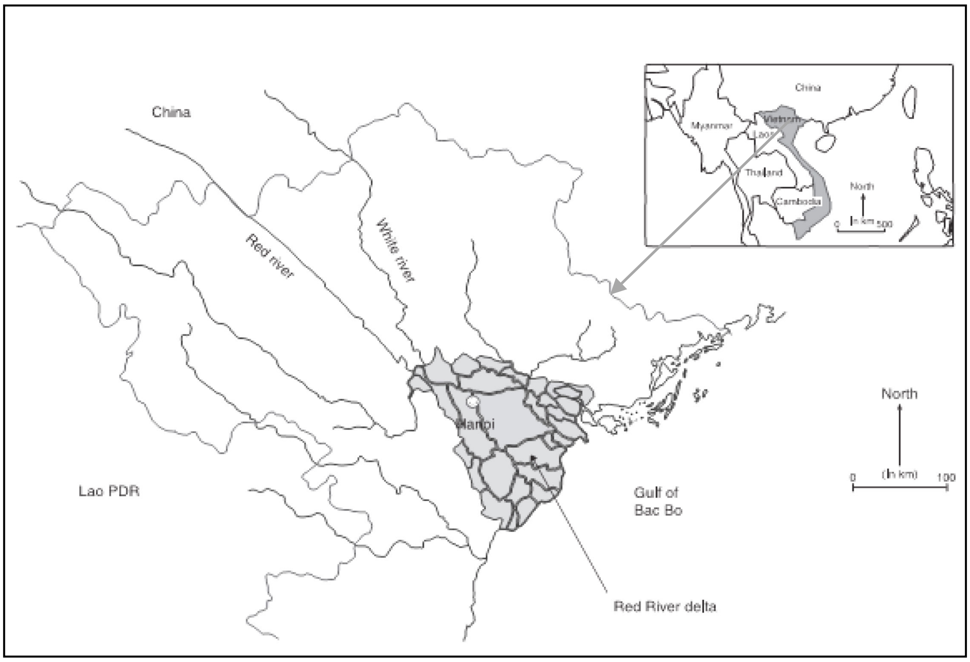

Figure 3.8. The Red River Delta in Vietnam (FONTENELLE *et al.* 2007)

The agricultural land area has had significant changes from 2001 to 2006, particularly (Table 3.8). The agricultural land area was decreased by 17.85 thousand ha (-1.82%) in 2006, in comparison with 2001. The agricultural production land: though some parts of agricultural land have been moved to other land use purposes, e.g. residential land, land for business premises, land for public works, and land for aquaculture, the total agricultural production land in 2006 was 756.26 thousand ha, reduced 41.59 thousand ha (-5.21%) compared with the year 2001 (GOS 2007).

The area for annual crops was decreased by 35.87 thousand ha (-4.98). The perennial crop land was reduced 5.72 thousand ha (-7.34%) form 2001 to 2006. Specially, the paddy land was decreased 6.10%, reduced by 40.50 thousand within five years. The aquaculture land was increased by 15.81 thousand ha. The increase in the aquaculture land was mostly concentrated in Hai Phong, Nam Dinh, Thai Binh province (GOS 2007).

Table 3.8. Change of agricultural land in Red River Delta *(thousand ha)*

	2001	2006	Change (2001-2006)	
			Quantity	Per.(%)
Total agricultural land	978.60	960.75	-17.85	-1.82
Agricultural production land	797.85	756.26	-41.59	-5.21
+ Annual crop land	719.90	684.03	-35.87	-4.98
Of which: Paddy land	663.88	623.38	-40.50	-6.10
+ Perennial crop land	77.95	72.23	-5.72	-7.34
Forest land	120.11	126.98	6.87	5.72
Land for aquaculture	58.90	74.71	15.81	26.84

Sources: GOS 2007

The total number of workable people in laboring age is about 3,870,057 persons (58.07% of total number of workable people in laboring age in the region) works in agricultural sector. The number of workable people in laboring age engaged in agriculture reduced rapidly (1,254,189 persons account for 24.48%) from 5,124,246 persons to 3,870,057 persons within five years (2001-2006). The average farm size in the Red River Delta is very small, about 0.3- 0.4 ha, with high fragmentation (GSO 2007).

3.3.1. Soil characteristics of Red River Delta

There are 7 main types of soil in the Red River Delta which were formed during the alluvial deposit, sedimentation, erosion, saltization, acidity (HOC 2001). The typical characteristic of the soil is thin and clearly divided into different layers (Table 3.9). The area has been used for paddy rice planting for long time, therefore the soil is getting acidity. There are several reasons for this, and the main ones are the soil is used unsuitably and little attention has been paid on conserving soil (HOC 2001).

Table 3.9. Characteristics soil in the Red River Delta

No	Characteristics	Alluvial area (fresh water)	Alluvial area which is salted	Alluvial area which is acidity
1	Soil horizon (m)	1.3	0.8	0.7
2	Cultivated surface containing humus (cm)	25	17	14
3	Amount humus in the upper layer (%)	2.5-3	1.7-2.2	1.5-2.0
4	pH (KCl)	5.5-6.5	6.7-7.0	4.5-5.5
5	P_20_5available (mg/ 100 gram soil)	1.25-2.5	Little	Little
6	Types of soil	Mid soil	Heavy soil	Heavy soil

Source: HOC 2001

3.3.2. Climate

The Red River Delta is affected by tropical climate. In winter, it is dominated by north-west wind characterized by low temperature and rainfall. In summer, it is dominated by southeast wind characterized by high temperature and rainfall.

Annually average temperature of Red River Delta from 2005 to 2008 is 24.3°C. The highest temperature in average for month is 30.3°C and the lowest 13,8°C. Temperature of summer months ranges from 24.5 -29.9°C. Average temperature of winter months such as Dec, Jan, Feb and Mar, is usually lower than 20°C (Figure 3.9).

Average rainfall is 1,733.3 mm and unevenly distributed. It is concentrated mainly on the period of April to October, with a rainfall of 1,538.1 mm or 88.74% of total rainfall. Particularly, there have been particular rains with one-day-rainfall exceeded 350 mm in November 1st 2008, it is highest rainfall within 100 years. In dry season, from November to March, the rainfall is placed at 195.2 mm or 11.26% of total rainfall (Figure 2.14) (HSO 2009).

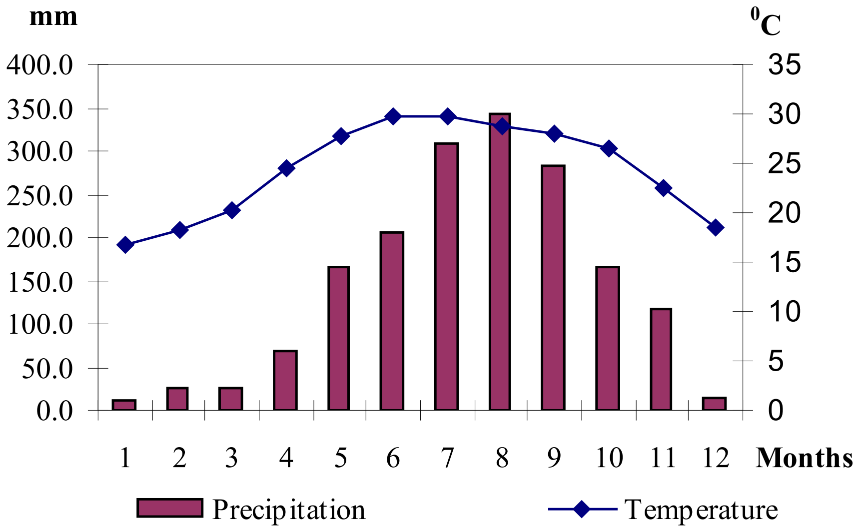

Figure 3.9. The monthly rainfall and temperature in the study area (2005-2008) (HSO 2009)

3.3.3. Agriculture and vegetable production in Red River Delta

Agricultural production in the Red River Delta is dominated by rice and other food crops. These account for 52% of gross agricultural production of the region. Whereas, vegetables account for 16%, cash crops 10% and animal husbandry 22%. In comparison with other countries, one ha of agricultural land in the Red River Delta produces an average of 1,560 USD which is a half of Japan where agriculture is heavily subsidized, or one third of Taiwan's (VIE/89/034 1995).

Under the new land law introduced in 1993, the land use rights are not only allocated to persons at working age in family as in collectivization period, but to all individuals in the family, meaning on a per capita basis, including the retired from military or civil services. Due to the possibility of transferring or exchanging land use rights to neighbors or others, average farm size thus increases. Plot scattering is reduced to only two or three plots compared with the 7 to 10 plots per farm household in the past this has increased the possibilities for farmers to invest in their farm.

In the past, vegetable production in the Red River Delta occurred in two ways. Farmers produced small amounts of vegetables for domestic consumption, and the state assigned specific cooperatives to produce vegetables. These were mostly cooperatives which were located nearby cities, so that they could supply urban markets, in which state companies were responsible for marketing activities. After the New Land Law introduced in 1993, agricultural production became more market oriented. Because of the high returns, vegetables became an important cash crop on which many small scale farmers concentrated, especially those living in areas nearby cities.

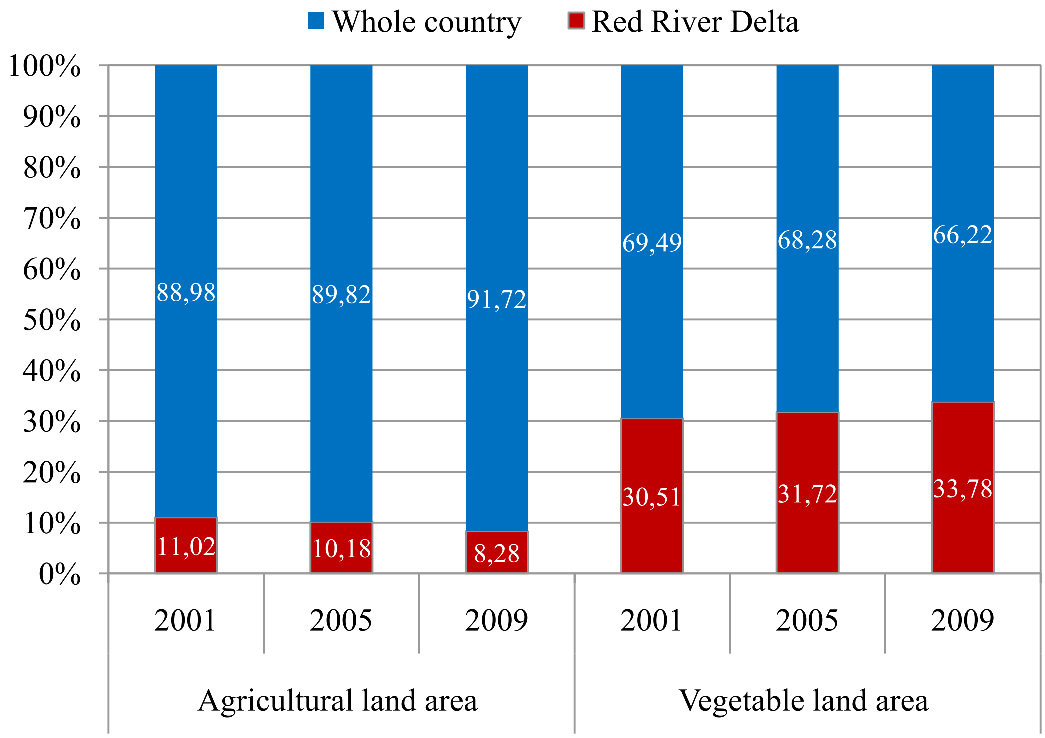

Figure 3.10. The agricultural land in whole country and vegetable area in the Red River Delta (MARD 2010 and GSO 2010)

The Red River Delta is the largest vegetables producer of the whole country with 219 thousand ha in 2009 increased 38% to compare with the year 2005 (Figure 3.10) (MARD 2010). Agricultural land area in Red River Delta accounted for 11% in 2001 and decreased to 8% of total cultivated land across the country in 2009. In the contrary, the vegetable cultivation area increased from 31 to 34% of total vegetable cultivation area in the whole country in the same period. In the Red River Delta, average farm size is around 0.25 ha. This land is comprised of on average 8 - 10 non contiguous plots of land, some of which are only 200 -500 m^2 in size (HUNG *et al.* 2004).

In parallel with increased of cultivation area, the production of vegetable in the Red River Delta increased remarkably with 39% from 2,852.8 in 2005 to 3,957.3 thousand tones in 2009 (Figure 3.11) (MARD 2010).

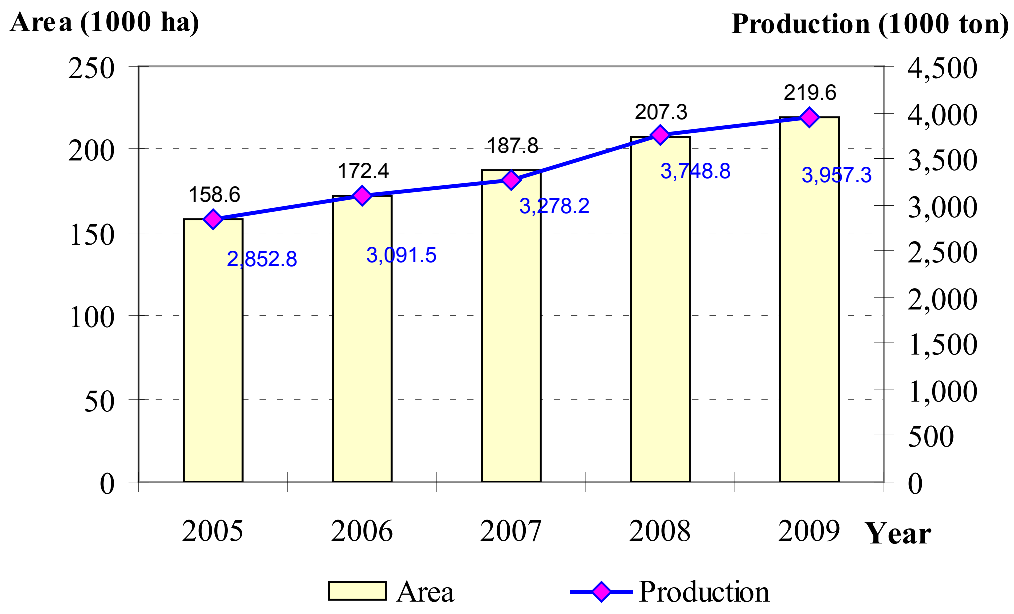

Figure 3.11. The vegetable production in the Red River Delta (MARD 2010)

3.4. Toward sustainable agriculture in Vietnam

In 2004, Agricultural Development Denmark -Asia and the Vietnamese National Farmers Union commenced a project to train farmers in organic agriculture and to develop the local market for organic crops. The pilot phase of the project involves 117 farmers in six provinces across Northern Vietnam (approximately 20 farmers in each province). The project involves a number of different commodities, with vegetables in Bac Ninh, Vinh Phucand Lao Cai Provinces, oranges in Tuyen Quang Province, litchis in Bac Giang Province and fish in Hai Phong Province. A farmer field school approach is used for training farmers.

The Vietnamese Ministry of Agriculture and Rural Development have developed some organic standards for Vietnam but their status remains unclear. Currently, the standards serve more as a guide to farmers and processors rather than a concrete tool for certification (IGCI 2007). The regulations do allow for private companies to issue organic certification for products destined for the domestic market, but since the domestic market is so small there are few companies willing to invest in organic certification.

In 2008, the Ministry of Agriculture and Rural Development proposed the Vietnamese Good Agricultural Practice (VietGAP) (MARD 2009). VietGAP are standards and guidelines to assist individuals and/or organizations, producers and consumers to prevent risks of food safety, produce quality and workers in production, harvesting and post-harvest handling of fresh fruit and vegetables. These also serve to protect environment and use for product identification, traceability and recall. The target application of VietGAP is designed to assist individual and/or organization inside or outside Vietnam to produce, assess and certify the safety of fruit and vegetables which are produced in Vietnam under the guidelines of Vietnamese good agricultural practices.

4. AIMS OF THE STUDY

This chapter describes the specific aims of the study, research questions, objectives, and research hypotheses and the usefulness of the study. They are formulated based on the general background, specific problems and literature review as the explanation in the first three chapters.

4.1. Aims of the study

- To assess the sustainability of vegetable cultivation systems in urban, peri-urban and rural regions of the Red River Delta based on three dimensions of sustainability.
- To assist in the development of a strategy for environmentally friendly and economically production of clean vegetables.

4.2. Research questions

1. How is the existing situation concerning to the sustainability of the vegetable cultivation systems in the Red River Delta in Vietnam
2. What is the sustainability level of different vegetable cultivation systems in the study area?
3. What is the direction of vegetable productions in terms of qualitative, quantitative, and environmental sustainability that would meet human's living standard demand and sustainable development in the future?

To answer these questions above, the objective of this study provides scientifically valid answers to these important questions.

4.3. Objectives of the study

1. To characterize vegetable cultivation systems in rural, peri-urban and urban area;
2. To evaluate the sustainability of different vegetable cultivation systems based on ecological, economic and social indicators.
3. To compare three different methodologies for sustainability assessment.
4. To detect the limitations in each vegetable cultivation systems and to formulate the recommendations.

4.4. Research hypotheses

- Vegetable cultivation systems in the Red River Delta give profitability to the farmers.
- Existing vegetable cultivation systems in the study area are unsustainable.
- Different sustainable assessment approaches give different sustainability indexes.

4.5. Usefulness of the study

1. This research will provide a multi-dimensional investigation of the vegetable cultivation systems in the Red River Delta in order to improve the sustainability.
2. The farmers can be aware of the relations between sustainability and profitability of their vegetable cultivation system.
3. It became visible by the farmers whether there are barriers for the productivity of vegetable cultivation systems used.
4. The results from this research will support the farmers and policy-makers in order to improve the management of:
    - The natural resources.
    - Better crop management.
    - Identification and introduction of appropriate production technologies, and
    - Better handling and marketing of the products.

All of these management supports could contribute to achieve the goal of sustainable vegetable production in the future.

5. RESEARCH METHODOLOGIES

This chapter describes the methodological approaches of sustainability assessment. The chapter starts with research framework, the method for collecting data and data management. The details of tools for sustainability assessment by multi-criteria evaluation method, by fuzzy evaluation method and sensitivity analysis are given in the rest part of this chapter.

5.1. Research design, sample and sampling

5.1.1. Research framework

This study has used both qualitative and quantitative approaches of scientific inquiry to explore the answers of the stated objectives. The framework of this study is represented in figure 5.1.

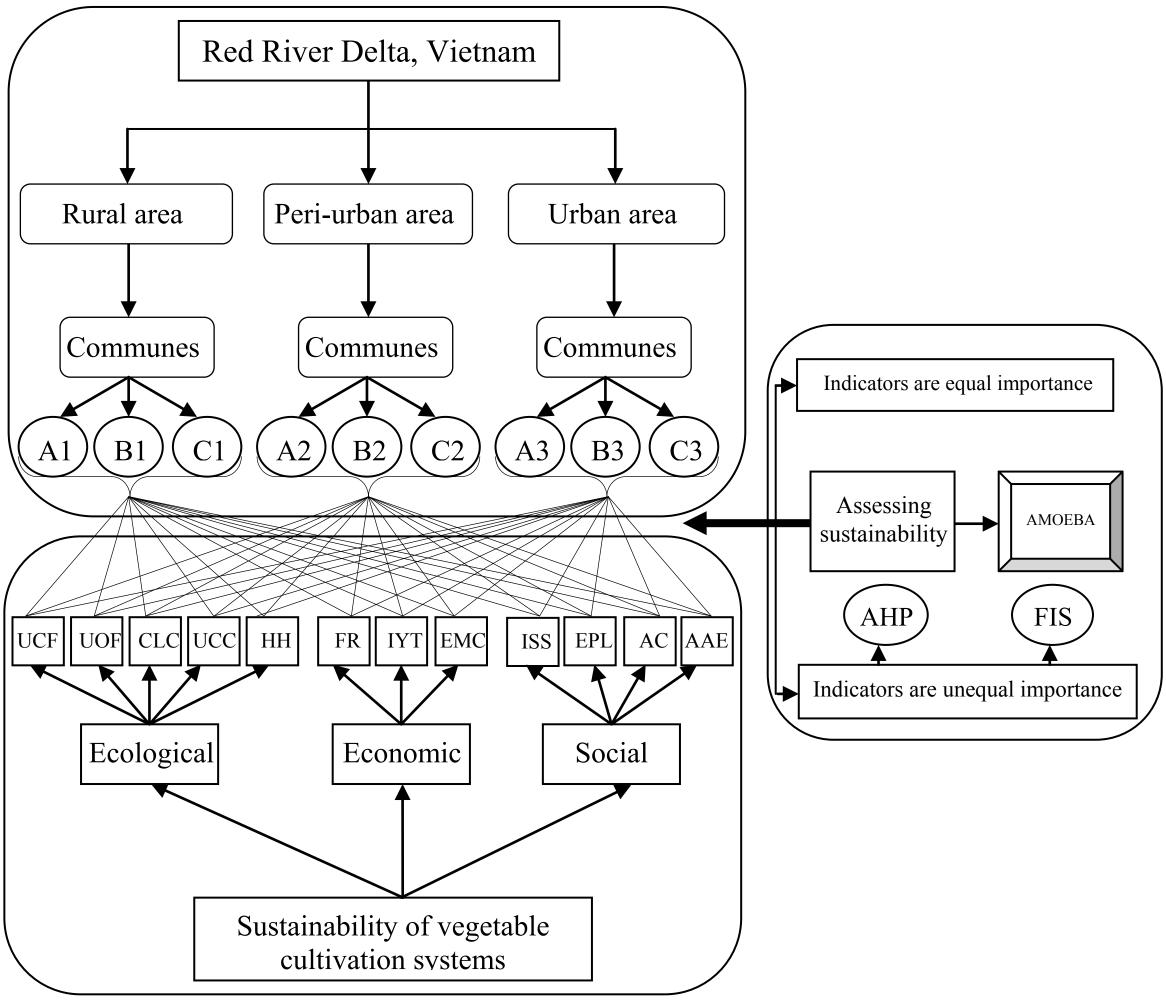

Figure 5.1. The framework for sustainability assessment of vegetable cultivation in the Red River Delta, Vietnam

In the figure 5.1 the abbreviations are explained as following:

AAE:	Access to agricultural extension
AC:	Access to Credit
AHP	Analytic hierarchy process
CLC:	Cultivation of legume crops
EMC:	Efficient of market channel
ECOLsus:	Ecological sustainability
ECONsus:	Economic sustainability
EPL:	Employment
FIS	Fuzzy inference systems
FR:	Financial return
HH:	Human health
IYT:	Index of yield trend
ISS:	Input self-sufficiency
Osus:	Overall sustainability
SOCsus:	Social sustainability
UCF:	Use of chemical fertilizer
UCC:	Management of pests and diseases (use of chemical control)
UOF:	Use of organic fertilizer

Figure 5.1 shows the framework of the study for sustainability assessment of vegetable cultivation systems in three regions with different types of land use - rural area (MeLinh district); in the peri-urban area (ThanhTri district); and in the urban area (HaDong district) in the Red River Delta, Vietnam. The main exploration of this study is based on qualitative analysis using structured questionnaire survey. Twelve criterions were used covering three dimensions of agricultural sustainability (Figure 2.2) by using three sustainability assessment approaches. The following sections present the detail of the rational of the choice of those criterions and methods for sustainability assessment.

5.1.2. The sample and sample size selection

The selection of three vegetable cultivation systems including urban, peri-urban and rural vegetable cultivation systems of Hanoi is based on the following criteria:

- Have experience with vegetables cultivation, daily supply of vegetable to the market;
- Representative for the urban vegetables cultivation system;
- Representative for the peri-urban vegetables cultivation system;
- Representative for the rural vegetables cultivation system;

- The outputs from the study in there communes can be applied in other area in Hanoi and Red River Delta.

Based on literature and the discussion with related departments of Hanoi, nine communes were selected belonging to three districts that represent for urban, peri-urban and rural vegetable cultivation systems (Figure 5.2).

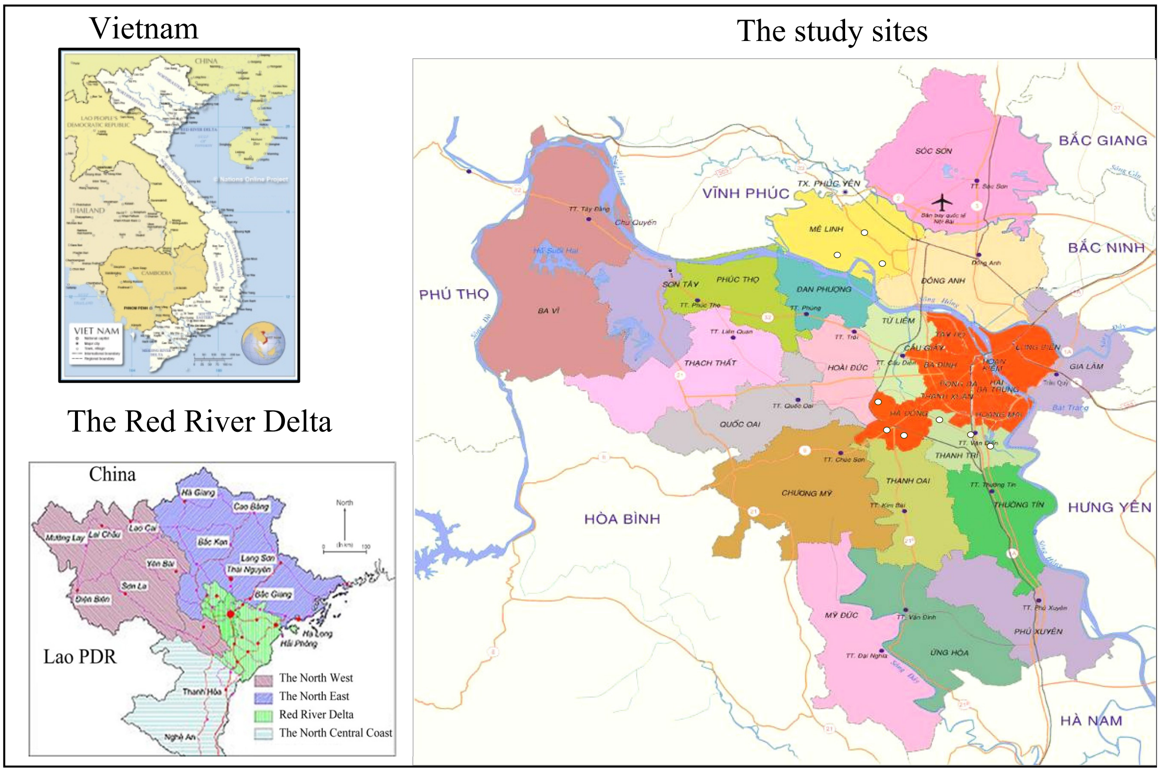

Figure 5.2. The study sites (nine communities were selected and represented in the black dots)

Each household was selected by using simple random technique, which is available in many computer programs. The random selection was applied in each commune. The random selection procedures are as follows:

- Listing all farm households.
- Inputting all farm households in to excel files.
- Using a random number generator in Excel "Rand ()" function to assign each farm household a random number.
- Using "Sort" command to sort farm households according to their random values.
- Selecting farm households based on their ranking.

An example, there were 137 households cultivating vegetable in Tienphong commune. I selected 14 farm households (Table 5.1) with their random number ranking ascending from 1st to 14th.

Table 5.1. Number of farm household per farming type

Vegetable cultivation systems	Communities			Total
Urban	Biengiang 11	Dongmai 11	Duongnoi 11	33
Peri-urban	Nguhiep 11	Tamhiep 11	Thanhliet 11	33
Rural	Tienphong 14	Daithinh 11	Vankhe 11	36

This technique is appropriate since every farm household in each commune has an equal chance of being selected. In addition, the simple random sampling technique in one or more stages is simple and easy to manage compare to other techniques like purposive and non-random sampling method (WOLFF1995 cited by SATTARASART 1999).

The sample size is based on (i) the number of farm households in each commune (ii) statistical requirements for analysis (iii) time and budget available (iv) the degree of homogeneousness of the population. The sample must be large enough to avoid the error or bias in the results of analysis.

5.1.3. Methods and procedures of collecting data

The procedures of collecting and analyzing data are depicted in figure 5.3. Primary data was collected at farm/household level. Questionnaires were designed for data collection from selected farm/households to collect qualitative and quantitative data on household and farm variables and to explore the perceptions, history, challenges and opportunities of vegetable production. In order to gather sufficient and accurate information, questionnaires were pre-tested and appropriate modifications in the instrument were made.

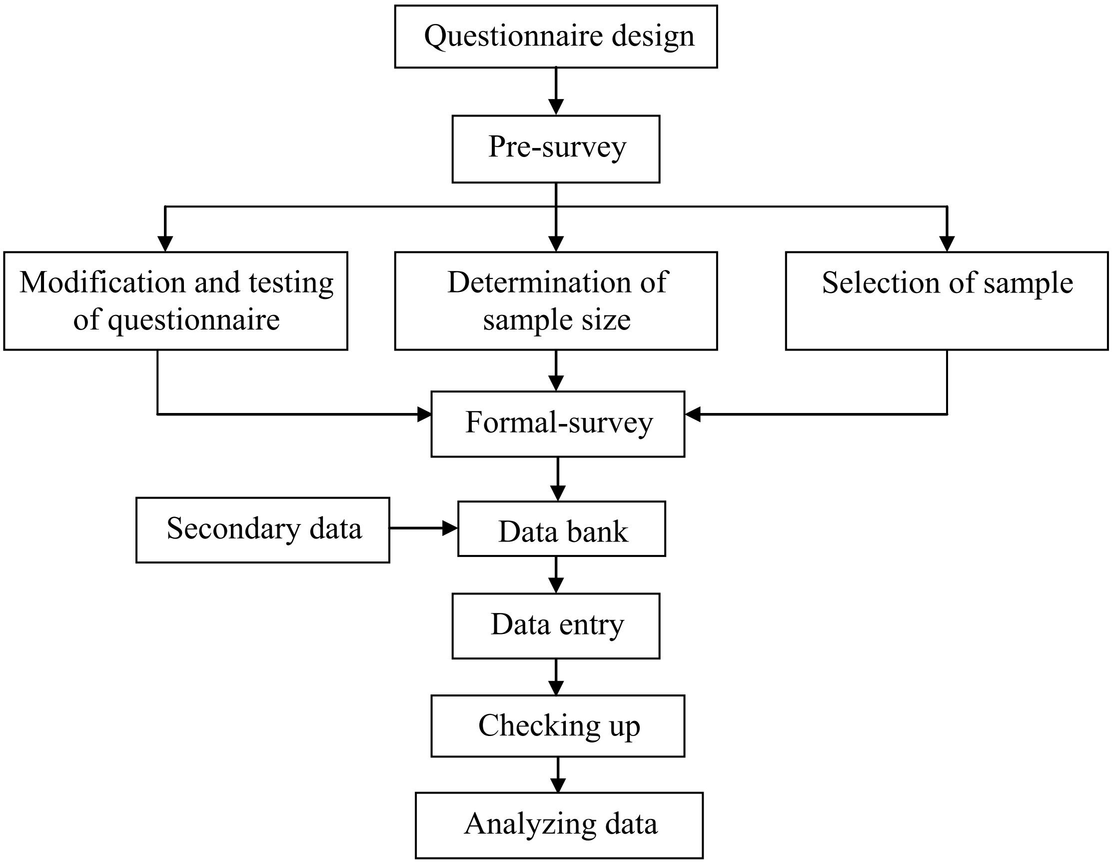

Figure 5.3. The procedures of collecting and analyzing data

Key informant interview was conducted to understand the direction of vegetable production and the challenges facing the vegetable production in Vietnam and for cross checking data from other sources.

Participant observation was carried out to gain an understanding of the agricultural activities in the study sites.

Three workshops were organized to define the score weight of each factor according to Analytic Hierarchy Process, AHP (SAATY 1980), and workshops were carried out to determine the rule for fuzzy inference system.

Secondary data was collected from the existing literature, various organizations and departments, including government institutions, data archives, research centers, NGOs to gain additional information.

5.1.4. Crosschecking data

Triangulation was used to ensure the validity of the data collected in this study. Triangulation involves collecting data from a number of different sources and in a number of different ways, and then crosschecking to ensure that the results match up (CHAMBERS

1994). As LEWIS and RITCHIE (2003) point out, triangulation "assumes that the use of different sources of information will improve the clarity, or precision, of a research finding". In a practical sense, this meant asking the same questions of a number of different actors to see if their version of data analysis events is similar, and gathering the same information in a number of different ways, for example, through the use of interviews, group discussions and observation. The results were also crosschecked against those reported in secondary sources where these were available. Data produced from the questionnaire instruments were entered into Microsoft Excel and rechecked with the raw data for accuracy.

5.2. Method for data analysis

5.2.1. Financial analysis

Financial analysis of different vegetable cultivation systems was done; it can provide a transparent a decision-making framework that brings together estimates of the tangible and intangible benefits and costs of project, risks and uncertainties. It estimates whether a particular investment is worthwhile in terms of opportunity cost of capital, which of a set of options produces the best incremental net benefit, and it enables projects to be ranked in terms of priority for investment. Cost-benefit analysis is a widely tool for economic analysis for planning or evaluating a certain project or new technology. It is useful tool in which its main strength is an explicit and rigorous accounting framework for systematic cost-efficiency decision-making (RONALD and WILLIAM 1999). Financial cost-benefit analysis is also useful tool for exploring the attractiveness of new technology, for instance, land use option.

Data for cost and revenue of vegetable production was analyzed. The farm record data was analyzed and average quantity and cost of various inputs (such as seed, fertilizer, herbicide and fungicide) used per ha was computed for each group of vegetable production for comparison. Furthermore, labor use (man-days per ha) and its associated cost per ha by type of operation was analyzed and compared rural, peri-urban and urban vegetable cultivation systems. Labor use and cost per ha by operation were segregated into family and hired labor to gain a better understanding of the composition of labor and distribution of cost.

- Gross margin (*GM*) was calculated as equation 5.1 (KAY and EDWARDS 1999) and used to compare between different vegetable cultivation systems.

$$GM = GR - TVC \tag{5.1}$$

Where: *GM*: Gross margin,

GR: Gross revenue,

TVC: Total variable costs.

Note: Price here refers to as the "farm gate" price of market price deduct by transportation cost to market and transaction cost in marketing.

Gross revenue

Gross revenue (*GR*) is defined as the value of the total vegetable output produced. Gross revenue was computed by multiplying average yield by average price at farm gate level (price of market price deducted by transportation cost to market and transaction cost in marketing). Gross revenue included the output produced during the year, which may be sold, used for household consumption, used for payments in kind for labor. GR was calculated following the equation 5.2 (KAY and EDWARDS 1999).

$$GR = \sum_{j=1}^{n} Q_j * P_j \tag{5.2}$$

Where: *GR:* Gross revenue

Q_j: The output of system j

P_j: Price of the output of system j

Total variable costs

Total variable costs (*TVC*) was calculated following equation 5.3 (KAY and EDWARDS 1999).

- Material cost - seeds, fertilizer, manure, plant protection cost.
- Labor cost - family labor cost, hire labor cost.
- Other cost - land preparation cost, cost for irrigation.

$$TVC = \sum_{i=1}^{n} P_i * X_i \tag{5.3}$$

Where: *TVC*: Total variable costs.

P_i: Price of the variable input i.

X_i: The quantity of variable input i.

5.2.2. Determinate the index of indicators

Trend of indicators such as yield trend, market channel, labors trend involved, chemical fertilizers, organic fertilizers and community health status were estimated based on farmer's subjective judgment to a question related those indicators. The index was constructed based on the following formula 5.4 (GOLAM and GOPAL 2003).

$$ITY = \left[f_i \times 1 + f_d \times (-1) + f_c \times 0\right]/n \tag{5.4}$$

Where: *ITY:* index of trend of yield, market, labors...

fi : frequency of responses indicating increasing yield, market, labors...

fd : frequency of responses indicating decreasing yield, market, labors...

fc : frequency of responses indicating constant yield, …..

n: total number of responses.

5.2.3. Descriptive data analysis

The data from semi-structured interview, formal survey and interview were analyzed using descriptive statistics such as percent, mean, standard deviation values and index to compare the different characteristics of all sustainable indicators for vegetable cultivation systems in the study area using One-way ANOVA analysis in SPSS 15.0 software.

5.2.4. Normalization of criteria

Instead of using the raw data for each indicator directly, the data was normalized to obtain a common scale and allow statistical aggregation. There are different normalization methods for indicator criteria. Normalization of indicators avoid scale effects for the averaging and solve the problem due to the fact that some indicators are of the type "more is better" and some other are of the type "less is better" (ALLARD *et al.* 2004). Normalize function were used to a common scale and allow statistical aggregation. Let *vi* be the data value of indicator i. Then its normalized value *I*(*vi*) is calculated as in equation 5.5 - equation 5.9 (ALLARD *et al.* 2004):

- ❖ If the target value T(*vi*) corresponds to maximum:

$$I(v_i) = \begin{Bmatrix} \dfrac{v_i - \min(s)}{T(v_i) - \min(s)} \text{ for } v_i \leq T(v_i), \text{and} \\ 1 \text{ for } v_i \geq T(v_i) \end{Bmatrix} \tag{5.5}$$

- If the target value T(vi) corresponds to minimum:

$$I(v_i) = \begin{cases} 1 \text{ for } v_i \le T(v_i), \text{and} \\ \dfrac{\max(s) - v_i}{\max(s) - T(v_i)} \text{ for } v_i \ge T(v_i) \end{cases} \tag{5.6}$$

- If the target value T(vi) corresponds to an interval [minT(vi), maxT(vi)]

$$I(v_i) = \begin{cases} \dfrac{v_i - \min(s)}{T(v_i) - \min(s)} \text{ for } v_i \le \min T(v_i), \text{and} \\ 1 \text{ for } v_i \in [\min T(v_i), \max T(v_i)], \text{and} \\ \dfrac{\max(s) - v_i}{\max(s) - T(v_i)} \text{ for } v_i \ge \max T(v_i) \end{cases} \tag{5.7}$$

- If the target value T(vi) corresponds to “yes” or “no” statement

$$I(v_i) = \begin{cases} 0.5 \text{ for } v_i = T(v_i), \text{and} \\ 0 \text{ for } v_i \ne T(v_i) \end{cases} \tag{5.8}$$

Finally, the value of each linguistic variable is given by the average aggregation:

$$T = \frac{\sum_i I(v_i)}{n_i} \tag{5.9}$$

n_i = total number of indicators

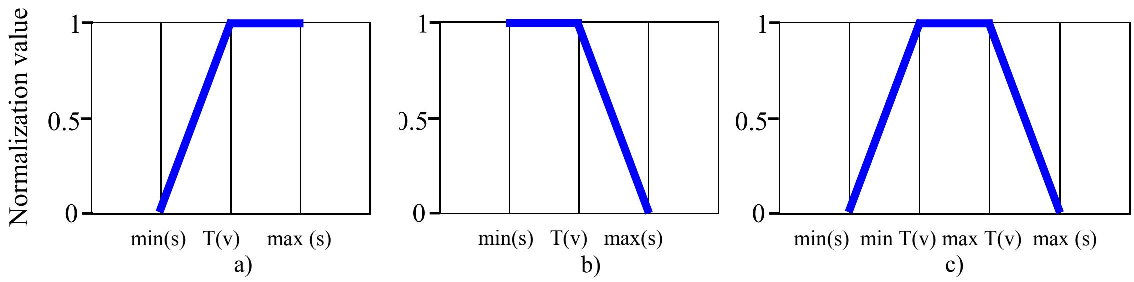

Figure 5.4. Examples of normalization
a) if the target is a maximum; b) if the target is a minimum; c) if the target is an interval
Adopted from PHILLIS and ANDRIANTIATSAHOLINIAINA 2000
Notes: T (v) = target values, min (s) = minimum values, max (s) = maximum values

5.3. Sustainability assessment methods

5.3.1. Sustainability assessment by multi-criteria evaluation method

5.3.1.1. Aggregation of indicators

The aim of Multi-criteria Evaluation is to choose the best or most preferred alternative, to sort out alternatives or to rank the alternatives in descending order of preference. The best solution is to combine indicators with each other to obtain overall value to assess the sustainability. There are different methods for aggregation and the set of weights in multi-criteria decision analysis problem. In this study, aggregation method to assess the overall sustainability was chosen as proposed by ALLARD *et al*. 2004.

The aggregation method for each indicator is according to the equation 5.10:

$$I_{sus} = \sum_{i=1}^{n} I(v_i) * w_i \tag{5.10}$$

The overall sustainability indicator (I_{sus}) is the result of the weighing average of all the normalized indicators I_i. w_i represents the weight of the ith indicator.

5.3.1.2. Criteria Weight

To compute the weigh factors of n elements, the input consists of comparing each pair of the elements using the following the scale set:

$$S = \left\{ \frac{1}{9},\ \frac{1}{8},\ \frac{1}{7},\ \frac{1}{6},\ \frac{1}{5},\ \frac{1}{4},\ \frac{1}{3},\ \frac{1}{2},\ 1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8,\ 9 \right\} \tag{5.11}$$

The pairwise comparison of element i with element j is placed in the position of aij of the pairwise comparion matrix A as bellowing:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{5.12}$$

The reciprocal value of this comparison is placed in the position a_{ji} of A in order to preserve consistency of judgment. Given n elements, the participating decision maker thus compares the relative importance of one element with respect to the second element, using the 9-point scale shown in table 5.2. The pairwise comparison matrix is called a reciprocal matrix for obvious reasons.

Table 5.2. The 9-point scale for comparisons

Importance	Definition	Explanation
1	Equal importance	Two elements contribute identically to the objective
3	Weak dominance	Experience or judgement slightly favors one element over another
5	Strong dominance	Experience or judgement strongly favors one element over another
7	Demonstrate dominance	An element's dominance is demonstrated in practice
9	Absolute dominance	The evidence favoring an element over another is affirmed to the highest possible order
2, 4, 6, 8	Intermediate value	Further subdivision or compromise is needed

Source: SAATY 1980.

After the pairwise comparison matrix is developed, the criterion weighing would be calculated, that step involves the following operations (MALCZEWSKI 1999): (i) sum the value in each column of the pairwise comparison matrix; (ii) divide each element in the matrix by its column total (the resulting matrix is referred to as normalized pairwise comparison matrix), and (iii) compute the average of the elements in each row of the normalized matrix. Their averages provide an estimate of the relative weights of the criteria being compared.

Consistency ratio was estimated. In this step involves the following operations (MALCZEWSKI 1999): (i) determine the weighted sum vector by multiplying the weight of the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column and so on multiply the nth weight times the nth column, finally sum these values over the rows, and (ii) determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously.

The consistency vector have been calculated, we need to compute values for two more terms, lambda (λ) and the consistency index (CI).

The value for lambda is simply the average value of the consistency vector.

Calculation of CI is based on the observation that λ is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrixes, and λ = n if the pairwise comparison matrix is a consistent matrix. Accordingly, λ = n can be considered as a measure of the degree of consistency. This measure can be normalized as follows (SAATY 1980):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{5.13}$$

The CI term, refer to as the consistency index, provide a measure of the departure from consistency. Further we can calculate the consistency ratio (CR), which is defined as follows (SAATY 1980):

$$CR = \frac{CI}{RI} \tag{5.14}$$

Where: RI is the random index (Table 5.3), the consistency index of a randomly generated pairwise comparison matrix. It can be shown that RI depends on number of elements being compared.

Table 5.3. Random consistency index (RI) for n = 1, 2, …, 15

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

Source: SAATY 1980.

The consistency ratio provides the user with a value that can be used to the judge the relative quality of the results. If the consistency ratio of less than 0.10 is obtained, then the results are sufficiently accurate, and further evaluation is not needed. However, if the consistency ratio is greater than 0.10, the results may arbitrary and the preferences should be re-evaluated or discarded.

5.3.2. Sustainability assessment by fuzzy evaluation method

To assess sustainability by fuzzy evaluation method, the following steps have to be defined and represented in figure 5.5 (adopted from PHILLIS and ANDRIANTIATSAHOLINIAINA 2000).

- Linguistic variables which best represent the sustainability of the whole system,

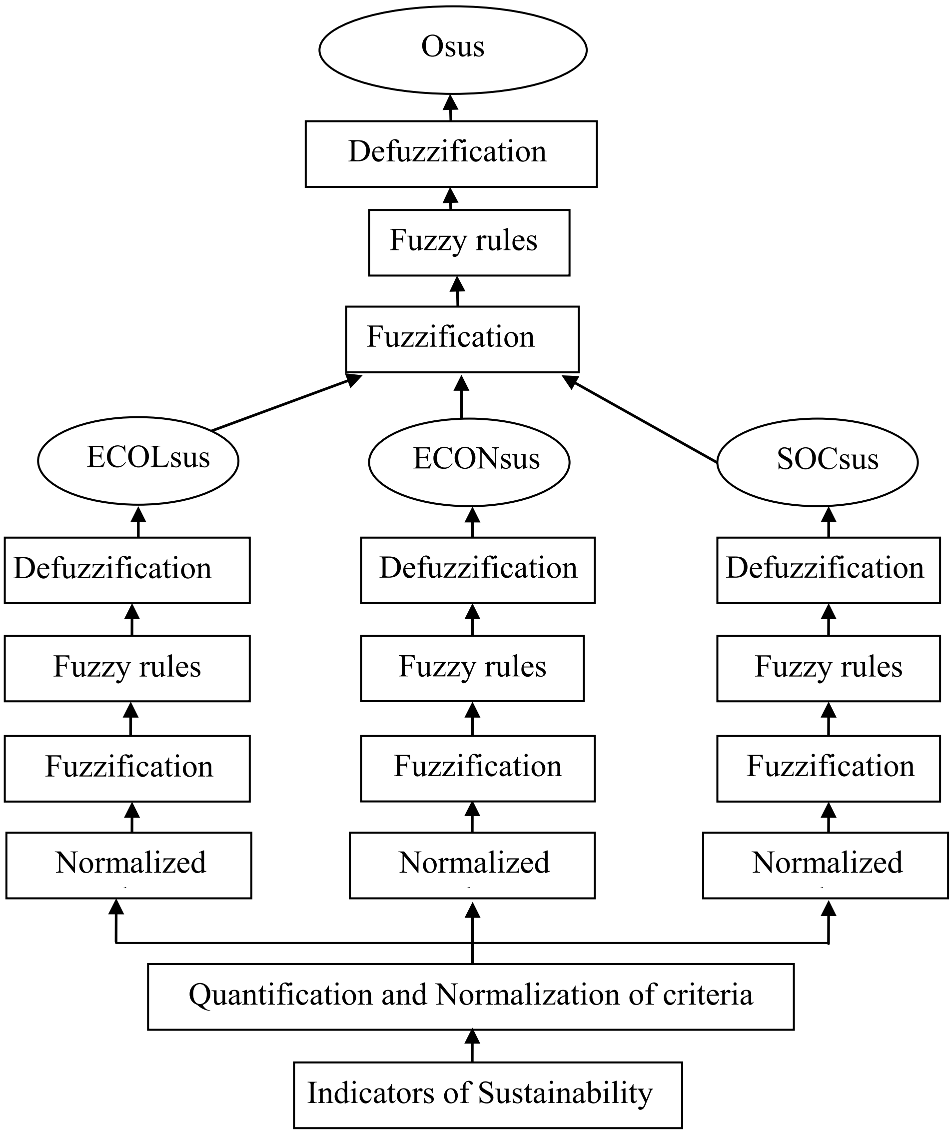

Figure 5.5. Methodology for the sustainability assessment by fuzzy evaluation method (PHILLIS and ANDRIANTIATSAHOLINIAINA 2000) (legends see figure 5.1)

- Linguistic rule bases and fuzzy logical operators which express qualitatively the knowledge and the key features of the overall system, and

- A defuzzification method to convert fuzzy statements into a single crisp value of overall sustainability.

5.3.2.1. The Linguistic variables definition and determination

Linguistic variable is defined by four items: (a) the name of the variable, (b) its linguistic values, (c) the membership functions of the linguistic values, and (d) the physical domain over which the variable takes its quantitative values (PHILLIS and ANDRIANTIATSAHOLINIAINA 2000).

The capability of each sustainability variable to fulfill criteria and principles of sustainability is called integrity. Criteria and principles of sustainability are recommended critical or target states which the system should satisfy to be sustainable. The primary linguistic variables of sustainability were assigned with Gaussian curve built-in membership function with five linguistic values:

1. Very Bad (VB),
2. Bad (B),
3. Satisfactory (S),
4. Good (G), and
5. Very Good (VG).

The linguistic values for the twelve secondary linguistic variables were assigned Trapezoidal-shaped built-in membership function with three linguistic values:

1. Low (L),
2. Medium (M), and
3. High (H)

5.3.2.2. The linguistic rules determination

Simulation of the evolution of the overall system is represented by rules of the form of “IF (antecedents) - THEN (consequent)”, where the implication operator “THEN” and the connectives “AND” among antecedents are fuzzy. The rules are expressions of the role of interdependencies among factors of sustainability. Economists, ecologists, and other experts consent that the components of sustainability should be set identical weight in an overall measurement (IUCN/IDRC 1995). This statement serves as the basis of the linguistic rule bases. Knowledge acquisition methodologies, such as interviews or questionnaires, can also be used to build the rules (ERICSSON and SIMON 1984). There are many ways to quantitatively express these fuzzy rules by choosing a specific mathematical representation of the "AND", "OR", and "IF-THEN" connectives (TSOUVERLOUDIS and PHILLIS 1998).

The process of acquiring fuzzy rule is an important process in fuzzy logic approach. Number of rules depends upon the number of linguistic classes present for each input parameter. In general form, number of rules needed can be written as L^n, where L is the number of linguistic classes and n refers to number of input variables (Figure 4.6). For example: if the number of linguistic classes are 5 and number of input variables are 3 then $5^3 = 125$ rules are needed.

For secondary variables; FR, IYT, HH… are associated with 3 linguistic classes. Primary variables; ECOLsus, ECONsus, SOCsus, and Osus are 5 linguistic classes.

For aggregation of ECOLsus, $3^5 = 243$ rules are needed.

For aggregation of ECONsus, $3^3 = 27$ rules are needed.

For aggregation of SOCsus, $3^4 = 81$ rules are needed.

For aggregation of Osus, $5^3 = 125$ rules are needed.

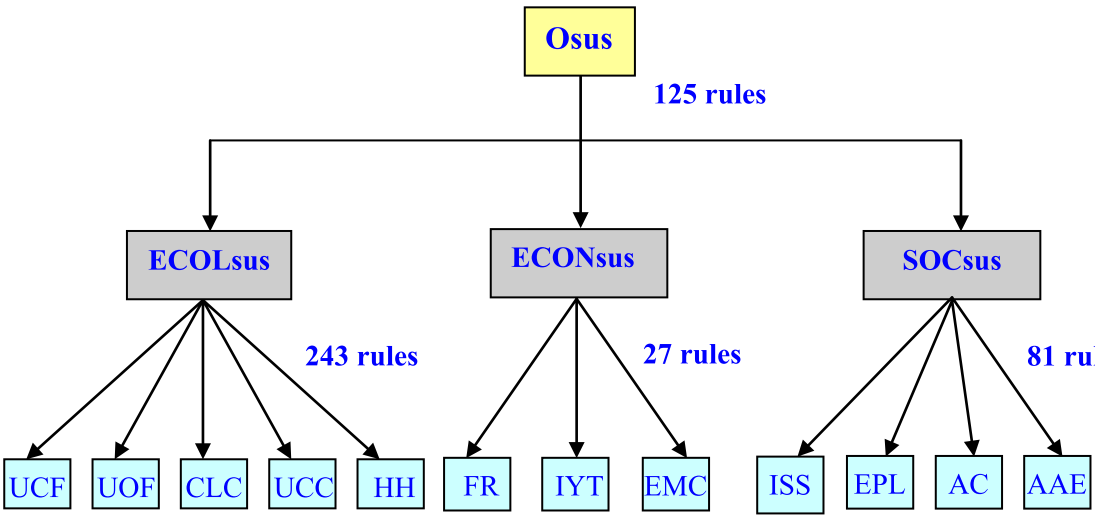

Figure 5.6. Number of rules required at different levels of aggregation (legends see figure 5.1)

5.3.2.3. Fuzzification methods

Fuzzification is the process of decomposing a system input and/or output into one or more fuzzy sets. Many types of curves can be used, but triangular or trapezoidal shaped membership functions are the most common because they are easier to represent in embedded controllers. Each fuzzy set spans a region of input (or output) value graphed with the membership. Any particular input is interpreted from this fuzzy set and a degree of membership is interpreted. The membership functions should overlap to allow smooth mapping of the system. The process of fuzzification allows the system inputs and outputs to be expressed in linguistic terms so that rules can be applied in a simple manner to express a complex system (MARCELO 2011).

Secondary variables

For secondary variables: FR, IYT, EMC, ISS, EPL, AC, AAE, UCF, UOF, CLC, UCC, and HH were assigned with Trapezoidal-shaped built-in membership function “trapmf”.

Trapezoidal membership function were chosen because they seemed to be more appropriate for representing membership degree of the linguistic values which have a certain range of the normalized crisp values. Besides, they are also commonly used in practical applications (BERKAN and TRUBATCH 1997, PEDRYCZ 1994). In general, a trapezoidal membership function can be defined as follows (MATHWORKS 2009):

Syntax

y = trapmf(x,[a b c d])

Description

The trapezoidal curve is a function of a vector, x, and depends on four scalar parameters a, *b*, *c*, and *d*, as given by:

$$f(x,a,b,c,d) = \begin{cases} 0, & x \le \mathrm{a} \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases} \tag{5.15}$$

or, more compactly as:

$$f(x,a,b,c,d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c} \right), 0 \right) \tag{5.16}$$

The parameters *a* and *d* locate the "feet" of the trapezoid and the parameters b and c locate the “shoulders” (MATHWORKS 2009).

- Membership functions and linguistic values were defined and represented in figure 5.7 and detained as follows:

  + MF1='low': 'trapmf', [-0.36 -0.04 0.2 0.4]
  + MF2='medium': 'trapmf', [0.25 0.4 0.6 0.75]
  + MF3='high': 'trapmf', [0.6 0.8 1.05 1.45]

Notes: trapmf = Trapezoidal-shaped built-in membership function,

MF = Membership Function

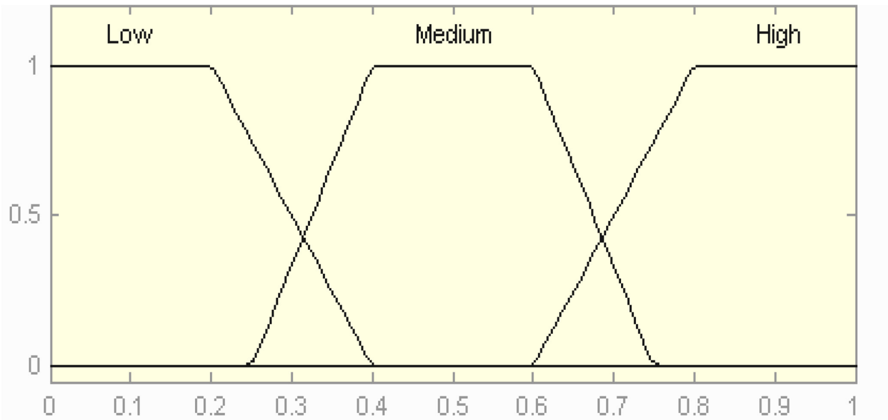

Figure 5.7. Membership functions for secondary variables

Primary variables

For primary variables: For primary variables: ECOLsus, ECONsus and SOCsus, and Osus were assigned with Gaussian curve built-in membership function “gaussmf”.

Gaussian membership functions are most adequate in representing uncertainty in measurement (KREINOVICH *et al.* 2011) and it has been found that Gaussian function is performing better than the trapezoidal function, as it demonstrates a smoother transition in its intervals, and the achieved results were closer to the actual effort (REDDY and RAJU 2009). In general, a trapezoidal membership function can be defined as follows (MATHWORKS 2009a):

Syntax

y = gaussmf(x,[sig c])

Description

The symmetric Gaussian function depends on two parameters σ and c as given by

$$f(x,\sigma,c)=e^{\frac{-(x-c)^2}{2\sigma^2}} \tag{5.17}$$

The parameters for gaussmf represent the parameters σ and *c* listed in order in the vector `[sig c]` (MATHWORKS 2009a).

- Membership functions and linguistic values were defined and represented in figure 5.8 and detained as follows:

  + MF1='Vbad': 'gaussmf', [0.1062 0]
  + MF2='Bad': 'gaussmf', [0.1062 0.25]
  + MF3='Satisfactory': 'gaussmf', [0.1062 0.5]
  + MF4='Good': 'gaussmf', [0.1062 0.75]
  + MF5='Vgood': 'gaussmf', [0.1062 1]

Notes: gaussmf = Gaussian curve built-in membership function.

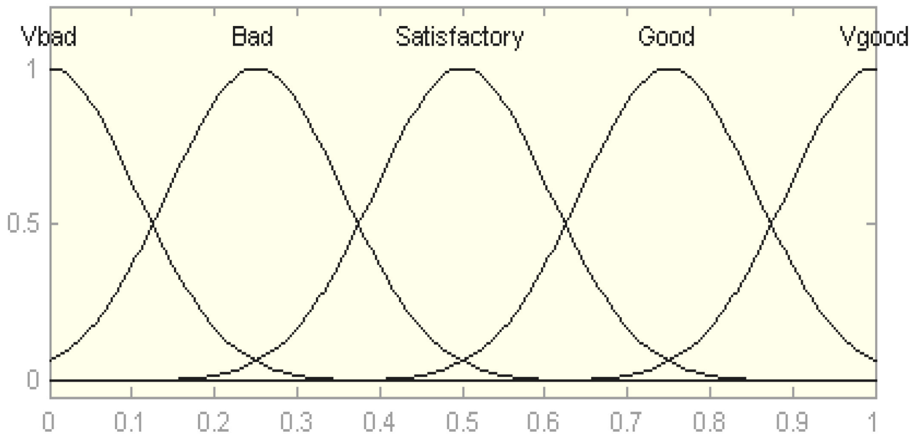

Figure 5.8. Membership functions for primary variables and overall sustainability

5.3.2.4. Aggregation process

The implication process evaluates individual rule over fuzzified grades and generates an output grade and output class. Now the Aggregation does two things. First it truncates the Consequent Fuzzy Set according to the grade obtained and secondly it does the Union of all these fuzzy sets. This aggregation process is done by Fuzzy Inference System (FIS) type Mamdani in MATLAB 7.1 program, fuzzy logic toolbox (Figure 5.9).

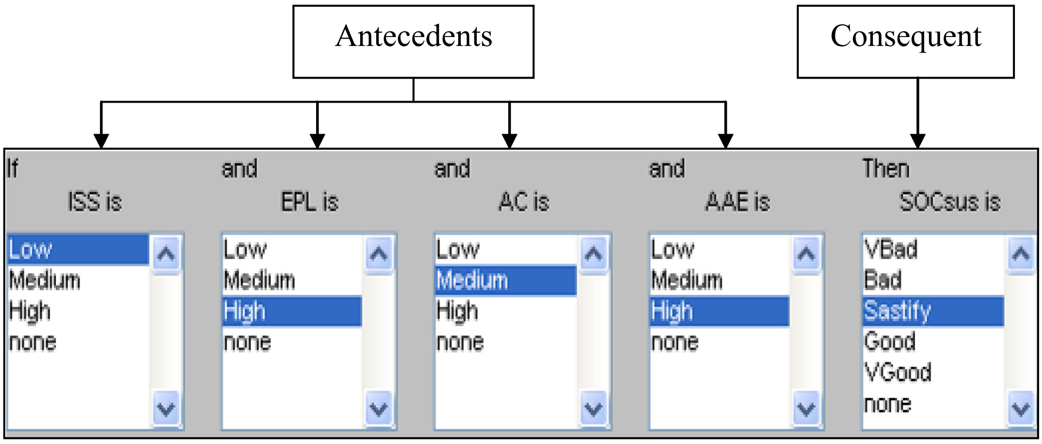

Figure 5.9. Fuzzy inference over indicator ISS, EPL, AC and AAE for aggregation

5.3.2.5. The defuzzification process

Defuzzification is the final operation that converts membership grades into a single crisp value. Several defuzzification methods have been presented in the literature (DRIANKOV *et al.* 1996).

After fuzzy reasoning we have a linguistic output variable which needs to be translated into a crisp value. The objective is to derive a single crisp numeric value that best represents the inferred fuzzy values of the linguistic output variable. Defuzzification is such inverse transformation which maps the output from the fuzzy domain back into the crisp domain. Some defuzzification methods tend to produce an integral output considering all the elements of the resulting fuzzy set with the corresponding weights. Other methods take into account just the elements corresponding to the maximum points of the resulting membership functions. The following defuzzification methods are of practical importance (PENG ZHANG 2008):

Center of area: The center of area method is often referred to as the Center-of-Gravity method because it computes the centroid of the composite area representing the output fuzzy term.

Center of maximum: In the center of maximum method only the peaks of the membership functions are used. The defuzzified crisp compromise value is determined by finding the place where the weights are balanced. Thus the areas of the membership functions play no role and only the maxima (singleton memberships) are used. The crisp output is computed as a weighted mean of the term membership maxima, weighted by the inference results.

Mean of maximum: The mean of maximum method is used only in some cases where the mean of maximum approach does not work. This occurs whenever the maxima of the membership functions are not unique and the question is as to which one of the equal choices one should take.

In this study the center-of-gravity was chosen because it conforms to the weighted-mean method that we use before fuzzification of the input which is the most frequently referenced in the literature.

5.4. Representation and assessment of the solution

To fulfill the objectives, representation must be clear and easy to understand. One tool which has proved to be useful to graphically integrate and monitor the different indicators is the AMOEBA or Radar diagram (LOPEZ-RIDAURA *et al.* 2002). The advantages of the AMOEBA diagram are first a clear and global representation of all the indicators and their associated value. Secondly, solutions can be easily to compare all indicators.

To achieve an adequate integration and synthesis of the results, the process of evaluation followed three major stages:

- Selection indicators of performance related to different perspectives (PASTORE and GIAMPIETRO 2000). A list of indicators of vegetable cultivation systems performance (and the range of their values) that can be used to reflect the various perspectives generated at district level is showed in section 2.2.1 (rational for the choice of sustainable indicators) and table 2.1.
- Defining feasibility domains for selecting indicators. Having chosen the variables on different axes, one must define a range of "feasible" values for each indicator (PASTORE and GIAMPIETRO 2000). Within the feasibility domain, the target values may be added to the graph that reflects the goals expressed by the representatives of different perspectives.
- Assessing current situation on a multi-dimensional state space (PASTORE and GIAMPIETRO 2000). In this step, the actual value of each indicator of performance is recorded on the graph. This makes it possible to visualize the position of the actual values. The results of integrating and monitoring the different indicators are presented in the AMOEBRA diagram in section 7.4 in chapter 7.

5.5. Sensitivity analysis

Sensitivity analysis is the study of how output variation in models can be apportioned, qualitatively or quantitatively, to different sources of variation in the assumptions (RAJESH *et al.* 2009). In addition, it measures how the given composite indicator depends upon the information that composes it. Sensitivity analysis is closely related to uncertainty analysis, which aims to quantify the overall variation in the countries' ranking resulting from the uncertainties in the model input (MICHAELA and ANDREA 2008). A combination of uncertainty and sensitivity analysis can help to gauge the robustness of the composite indicator, to increase its transparency, and to frame policy discussions (RAJESH *et al.* 2009).

5.5.1. Sensitivity analysis by using multi-criteria evaluation method

Multi-criteria evaluation methods, the sensitivity analysis involving weights consists of investigating the sensitivity of the alternatives to small changes in the value of attribute weights. If the rankings remain unaffected as the weights are varied, errors in the estimation of attribute weights can be consider insignificant (MALCZEWSKI 1999). By imposing some perturbation on the weights, we attempted to determine the degree to which output of the weighing procedure will change. The results of sensitivity analysis indicate that final ranking of sustainability for deference vegetable cultivation systems are stable or not. So that we can conclude the errors in components weight can be considered significant or insignificant.

5.5.2. Sensitivity analysis by using fuzzy evaluation method

In this assessment method, sensitivity analysis is applied by using different confidence levels for membership curve and by varying input values. In the fuzzy reasoning approach, two major parameters are considered to be its major strength and also its weakness. First one is the membership curve and second one is the Rules. According to JEGANATHAN (2003), in order to check the role of membership curve in the fuzzy model, three different types of membership curve were considered: Triangular, Gaussian and Trapezoidal. These Membership functions are considered as representation of different confidence levels of the decision maker. Triangular membership curve represents for the decision maker the least confident because it is very uncertain about belongingness of any value to a particular linguistic class except at one point for each. Trapezoidal curve represents for decision maker the most confident, because it is very certain about the belonging of certain range of values to particular class and Gaussian curve represent the moderate confidence level.

Moderate confidence (adopted from JEGANATHAN 2003): the membership functions were defined as figure 5.10 and set following:

+ MF1='Vbad': 'gaussmf', [0.1062   0.00]
+ MF2='Bad': 'gaussmf', [0.1062   0.25]
+ MF3='Satisfactory': 'gaussmf', [0.1062 0.5]
+ MF4='Good': 'gaussmf', [0.1062   0.75]
+ MF5='Vgood': 'gaussmf', [0.1062   1]

Notes: gaussmf = Gaussian curve built-in membership function.

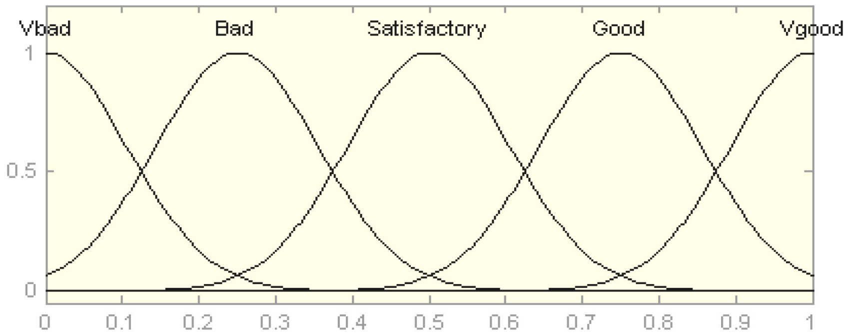

Figure 5.10. Membership curves with moderate confidence level

Least confidence (adoped from JEGANATHAN 2003): the membership functions were defined as figure 5.11 and set following:

+ MF1='Vbad': 'Trimf', [0 0 0.25]
+ MF2='Bad': 'Trimf', [0 0.25 0.5]
+ MF3='Satisfactory': 'Trimf', [0.25 0.5 0.75]
+ MF4='Good': 'Trimf', [0.5 0.75 1]
+ MF5='Vgood': 'Trimf'[0.75 1 1]

Notes: gaussmf = Gaussian curve built-in membership function,

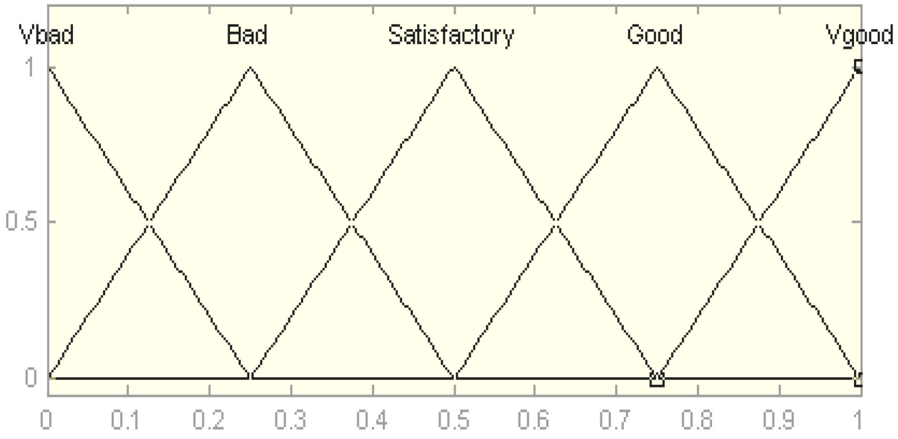

Figure 5.11. Membership curves with least confidence level

Most confidence: the membership functions were defined as figure 5.12 and set following:

+ MF1='Vbad': 'Trapmf', [0 0 0.025 0.225]
+ MF2='Bad': 'Trapmf', [0.025 0.225 0.275 0.475]
+ MF3='Satisfactory': 'Trapmf', [0.275 0.475 0.525 0.725]
+ MF4='Good': 'Trapmf', [0.525 0.725 0.775 0.975]
+ MF5='Vgood': 'Trapmf', [0.775 0.975 1 1]

Notes: trapmf = Trapezoidal-shaped built-in membership function.

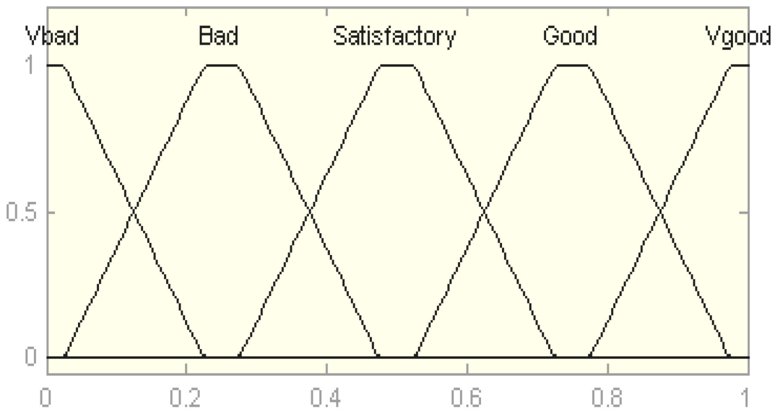

Figure 5.12. Membership curves with most confidence level

6. FIELD STUDY RESULTS

This chapter presents the results of the field study that including the results from primary and secondary data collection such as the land resources, human resources, and characteristics of the vegetable cultivation systems in the rural area (MeLinh district), in the peri-urban area (ThanhTri district), and in the urban area (HaDong district). The synthesizing results of all sustainable indicators of vegetable cultivation systems in the study area are represented.

6.1. Resource analysis

6.1.1. Human resources

Human resources play an important role for social - economic development. Labor is one of the main elements of the family resources. Labor division and gender play an importance in on-farm and off-farm activities, and is also important in vegetable cultivation systems.

6.1.1.1. Family size and composition

Family size and composition are important parameters in decision making process of the farm - household. They determine the capability and availability of labor for the farm and off-farm activities as well as consumption units.

Table 6.1 presents the family size and composition of different farm-household group in the study area in 2010. It can be seen from table that the average family size varies from 3.85 persons per household in urban group to 4.92 persons per household in the rural group. The family size are significantly different among the three groups of household (P= 0.00). Adults are persons in the range of 15 to 60 years old for the men and 15 to 55 for the women. There are highest in the rural group with 3.14 persons per household and lowest in the peri-urban group with 2.82 persons per household. However, there are not significant differences between three groups of household (P= 0.215). Old people are those whose age is greater than 55 and 60 years, respectively for the women and men. Children are those who are less than 15 year old. Number of old persons and children are statically different among the three groups, although the rural group has highest number of old people and children per household.

Table 6.1. Means and standard deviations (within parentheses) for family size and composition of farm household groups in the study area

Characteristics (persons/household)	Rural	Peri-urban	Urban	Sig.
	N = 36	N = 33	N =33	
Family size	4.92^{a} (0.84)	4.12^{b} (0.82)	3.85^{b} (0.62)	0.000
Adult	3.14 (0.90)	2.82 (0.81)	3.09 (0.67)	0.215
Men	1.50 (0.56)	1.39 (0.50)	1.42 (0.50)	0.684
Women	1.64 (0.72)	1.42 (0.56)	1.67 (0.48)	0.202
Children	0.86^{a} (0.68)	0.70^{ab} (0.68)	0.33^{b} (0.48)	0.002
Old persons	0.92^{a} (0.65)	0.61^{ab} (0.66)	0.42^{b} (0.61)	0.007

a, b: different letters within a row indicates significant difference between the means ($P<0.05$). (Synthesizing from household survey, 2009-2010)

6.1.1.2. Household labor force

A majority of the labor force in the study area has employment, the number of unemployed accounts for only a small share. The most common type of labor used in the study area for agricultural purposes is family labor. In the peri-urban area, more than 96% of the labor used is family labor, while the remaining 4% of labor used is hired labor. In rural area and urban area 99.7% and 99.8% of the labor used is family labor, and only 0.28 and 0.18% labor used is hired labor, respectively. On average, the number of days per worker per year for agricultural labor is approximately 37.6 days in the rural area, 27.9 days in the peri-urban, and 22 days in the urban area. The results indicate that the idle time of labors in Red River Delta is high. Wages average VND 65 thousand per day in the rural area, VND 100 thousand per day in the peri-urban and the urban area.

6.1.1.3. Household head education

There is significant difference between the education levels of household heads among regions in the study area (Figure 6.1). The highest education of household heads is belonging to urban area with 52% and secondary school with 48%.

The most common level of education for household heads is secondary school in the peri-urban area with 45% and high school account for 42%, and the rest of household heads 12% has their levels of education is primary school. The level of education for household heads has not completed primary school in the rural area account for 42%. 5.6% of the head of household in the rural area is illiterate, they could not read or write. About one-third of the heads of households have at least a secondary school education, and nearly 20% of head household has their level high school degree in the rural area. Overall, more than 35% of workers in the study area hold high school degrees; the proportion is 52% and 42% and 19% for urban, peri-urban and rural, respectively.

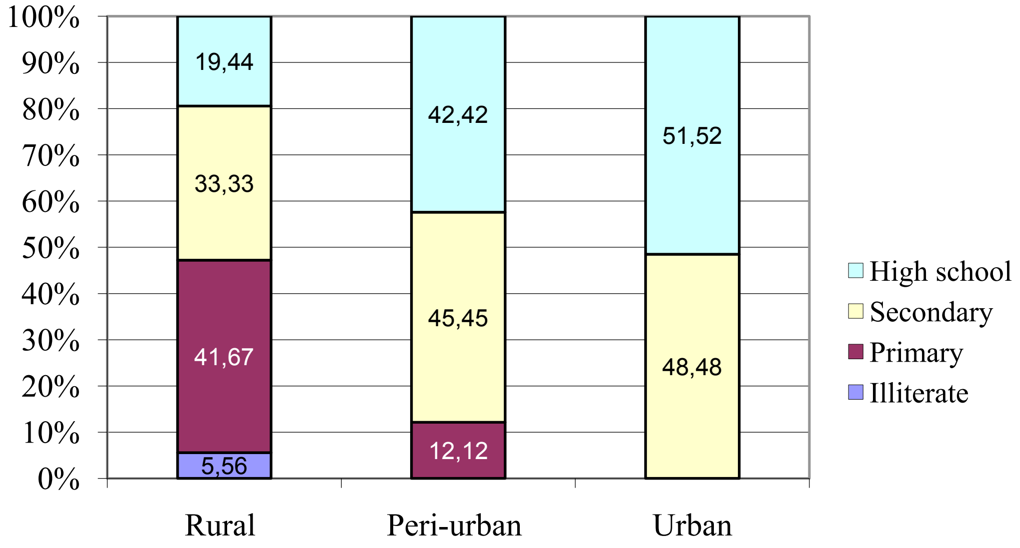

Figure 6.1. The education levels of education for household heads in the study area

6.1.1.4. Household head experience in growing vegetables

Most vegetable producers in study area started growing vegetables since 1986. An average of household head has 20 years, 17 years and 15 years experience in growing vegetables in the urban, rural and peri-urban area, respectively (Figure 6.2). In the figure 5.2 do not simply reflect the year the household starting growing vegetable. In 1990, 50% of the household heads in urban area are at least 18 years old, and households in urban area has fewer children, they could not be separate households, so the household head is elderly, but in peri-urban and rural areas has the new separate households, so the average years experience in growing vegetables of the household heads is lower.

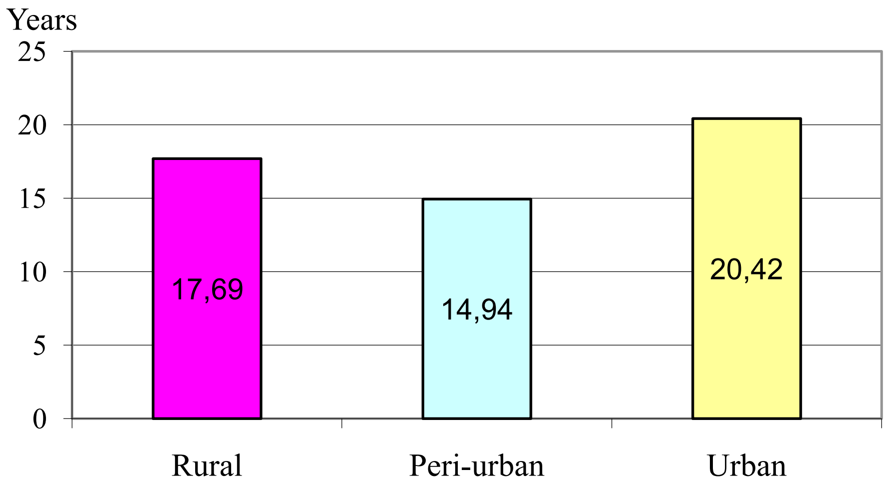

Figure 6.2. The household head experience in growing vegetables in the study area

6.1.2. Land resource

6.1.2.1. Agricultural land resource

In the rural area, the agricultural land has decreased, but less than the peri-urban and urban area, the agricultural land has decreased 28.65% between 2000 and 2009 (from 11,366 ha to 8,110 ha), the land area for vegetables increased significantly due to the restructuring of crops from rice to vegetables. The results show that a gradual but significant increase in the extent of vegetable cultivation area from 2,328 ha to 3,567 ha (53.22%) at the same duration (Figure 6.3, 6.6).

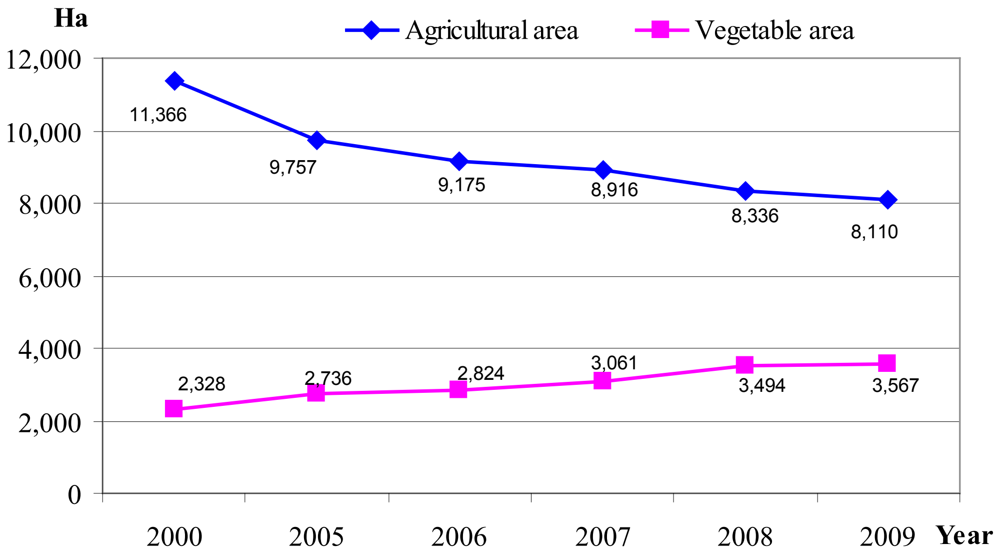

Figure 6.3. The agricultural area and vegetable area in the rural area (Melinh district) (MSD 2010)

Agricultural land in study area has decreased notably; especially in urban area caused by Hadong was a city under the former Hatay province, from the First of August 2008 Hatay became to Hanoi. Therefore, the Hadong district has been restructuring of land use, the agricultural land and also vegetable area has changed remarkable. The agricultural land and vegetable area in the urban area had been significant changed from 2000 to 2009 (Figure 6.4). The agricultural land decreased by 53.85% (3205 ha in 2000 with 1,479 ha in 2009 in comparison). The vegetable area decreased by 47.33% (from 1,458 ha in 2000 to 768 ha in 2009).

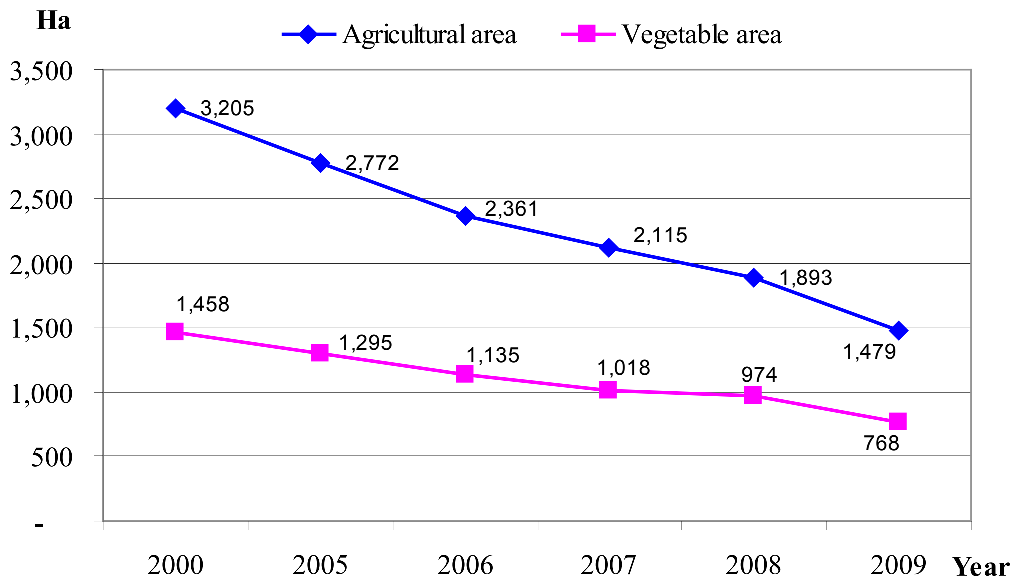

Figure 6.4. The agricultural area and vegetable area in the urban area (Hadong district) (HSD 2010)

Agriculture is threatened by urbanization: Agricultural land in Hanoi decreased significantly. During 1993 - 2008, Hanoi lost 5,400 ha (8.2%) of cultivated land for urban development (from 49% (43,000 ha) in 1993 to 40.8% (37,600 ha) of the area in 2008 (DINH and NGUYEN 2005 and GSO 2009).

Along with the development of the country, Thanhtri - peri-urban district could not be out from the urbanization. The agricultural land and vegetable area in the peri-urban area had been significant changed from 2000 to 2009 (Figure 6.5, 6.6). The agricultural land decreased by 36.67% (from 3,815 ha in 2000 to 2,416 ha in 2009). The vegetable production area decreased 34.84% (1,576 ha in 2000 with 1,027 ha in 2009 in comparison).

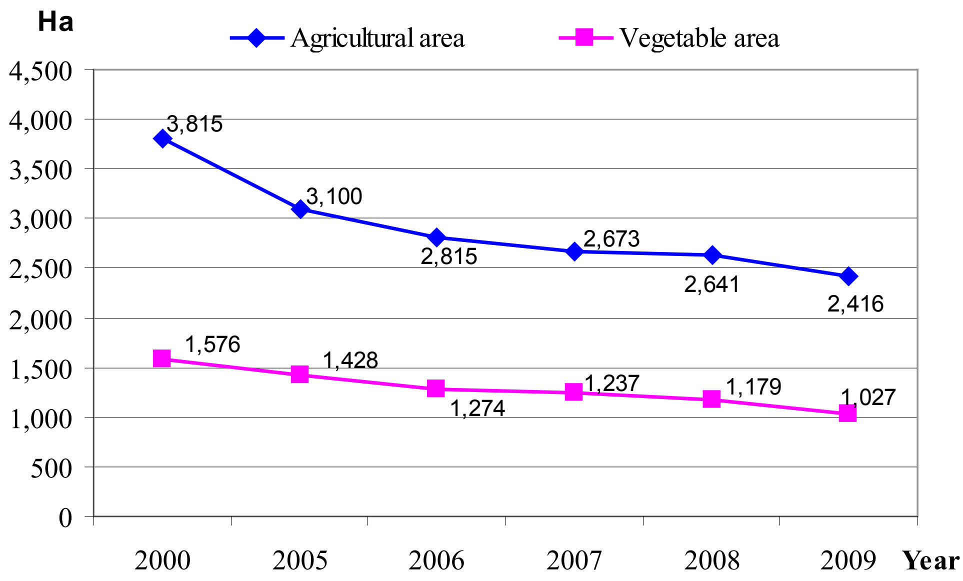

Figure 6.5. The agricultural area and vegetable area in the peri-urban area (Thanhtri district) (TSD 2010)

Figure 6.6. Vegetable area was shrunk due to urbanization (a) in MeLinh and (b) in ThanhTri district

6.1.2.2. Farm size and plot size

Farm-households in the study are small and fragmented. An average farm-household size is highest in the rural area (0.26 ha), 0.15 ha in the peri-urban area and the lowest in the urban area (0.11 ha) caused by high population pressure and demand for the competitive use of land from industries, housing, and infrastructure. This land is comprised of on average from 4.5 to 7.2 noncontiguous plots of land, some of which are only 200 - 500 m^2 in size (Table 6.2).

The majority of the agricultural land is allocated to vegetable production with the largest area for vegetable production belong to the rural area with 0.16 ha per farm-household accounts for 60.78% of total agricultural land of farms/households. The highest percentage of vegetable to compare with agricultural land is the peri-urban area with 83.18%, but the area just 0.09 ha per farm-household (Table 6.2).

Table 6.2. Means and standard deviations (within parentheses) of land holding size, plot size, vegetable cultivation, and legume cultivation in the study area.

Characteristics	Unit	Rural		Peri-urban		Urban	
		N = 36		N = 33		N =33	
Farm size	ha	0.255	(0.055)	0.152	(0.035)	0.107	(0.016)
Number of plots		7.167	(1.558)	5.697	(1.130)	4.515	(1.202)
Average plot size	ha	0.036[a]	(0.053)	0.027[b]	(0.003)	0.025[b]	(0.004)
Vegetable cultivated area	ha	0.155[a]	(0.037)	0.100[b]	(0.025)	0.089[b]	(0.016)
Legume cultivated area	ha	0.092	(0.022)	0.058	(0.024)	0.045	(0.019)

a, b: different letters within a row indicates significant difference between the means ($P<0.05$). (Synthesizing from household survey, 2009-2010)

In the rural and urban area, all of agricultural land is owned by farm-household, but in the peri-urban, most of the land for agriculture is owned by farm-household (92.26%) and 7.74% of the land is rented.

6.2. Production systems

6.2.1. Vegetable production system

6.2.1.1. Vegetable patterns

The crops calendar in the study area are summarized in figure 6.7 to 6.9, the farms in those communes are small-scale vegetable and/or mixed vegetable-rice farms. Multiple cropping seems to be relevant to the farmers with the small cultivated land, since a higher total yield and greater gross return per unit area can be obtained. In other words, multiple cropping may help farmers to cope with land shortage. There are 10 types of vegetable grown in the study area, including bean, leafy cabbage, onion, headed cabbage, cauliflower, kohlrabi, sweet pepper, cucumber, tomato, water morning glory. Leafy cabbage covered a wide variety in all vegetable cultivation systems. It is the main vegetables and easy to find either on separate field or parcels.

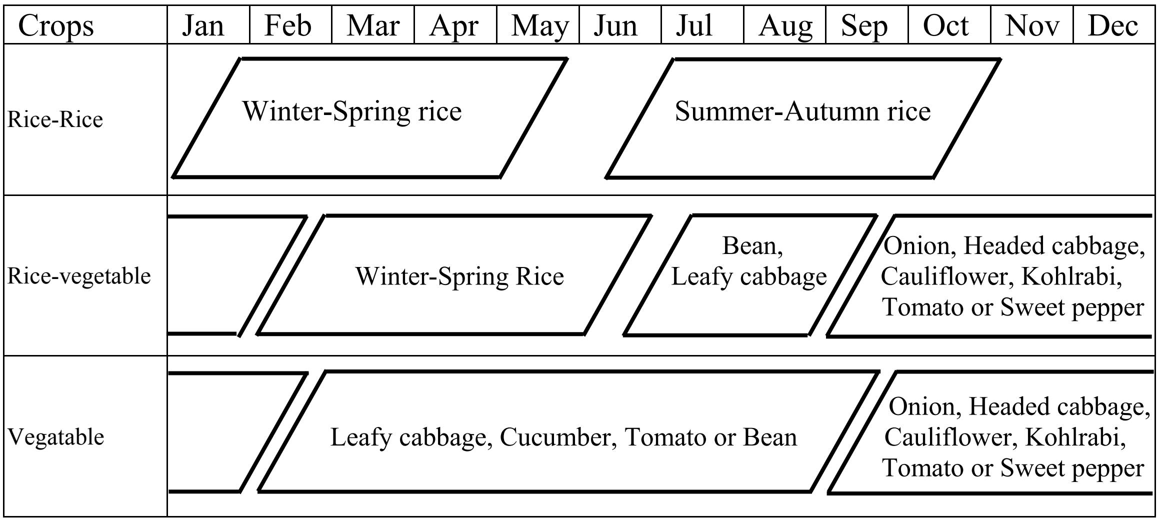

Figure 6.7. The cropping patterns in the rural area (Melinh district) (Synthesizing from household survey and group discussion, 2009-2010)

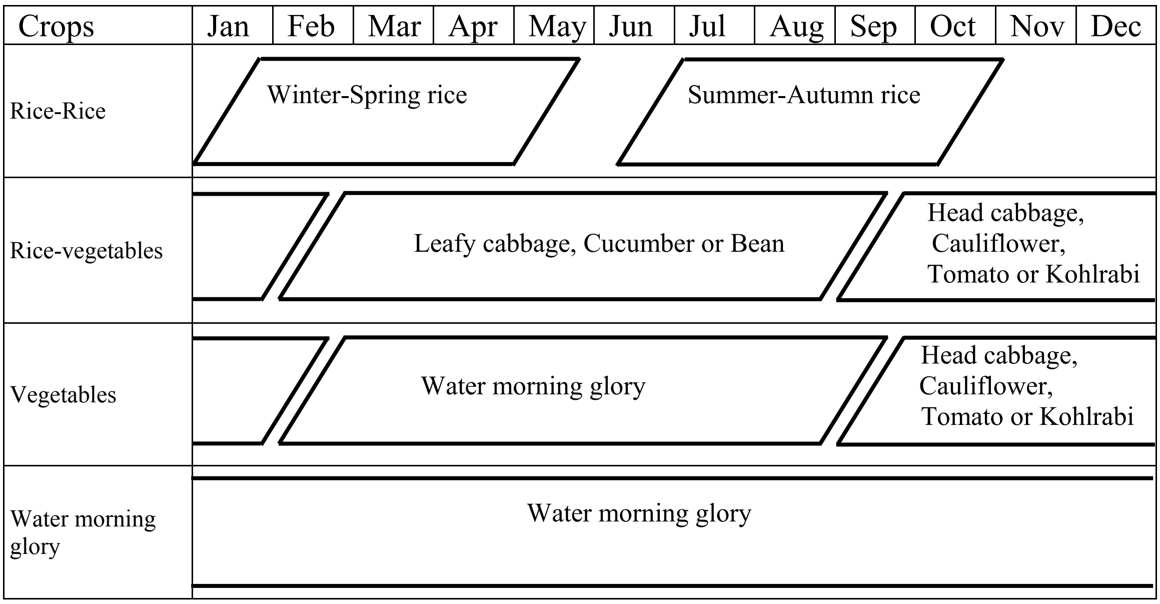

Figure 6.8. The cropping patterns in the peri-urban area (Thanhtri district) (Synthesizing from household survey and group discussion, 2010)

The crops calendar in the study areas could be divided into two types of cultivation systems that are rice-based systems and vegetable-based systems. In the rice-based systems, mono-crops of rice such as Winter-Spring rice is harvested at the end of May - beginning June and Summer-Autumn Rice crop is harvested at the end of October-beginning of November; and there is Winter-Spring rice that is harvested at the end of May - beginning June and rotation with vegetable. In the vegetable-based systems, vegetables are grown year around and rotation. Most of the farmers grow a combination of leafy vegetable, root vegetable (onion) and fruit vegetables (tomatoes).

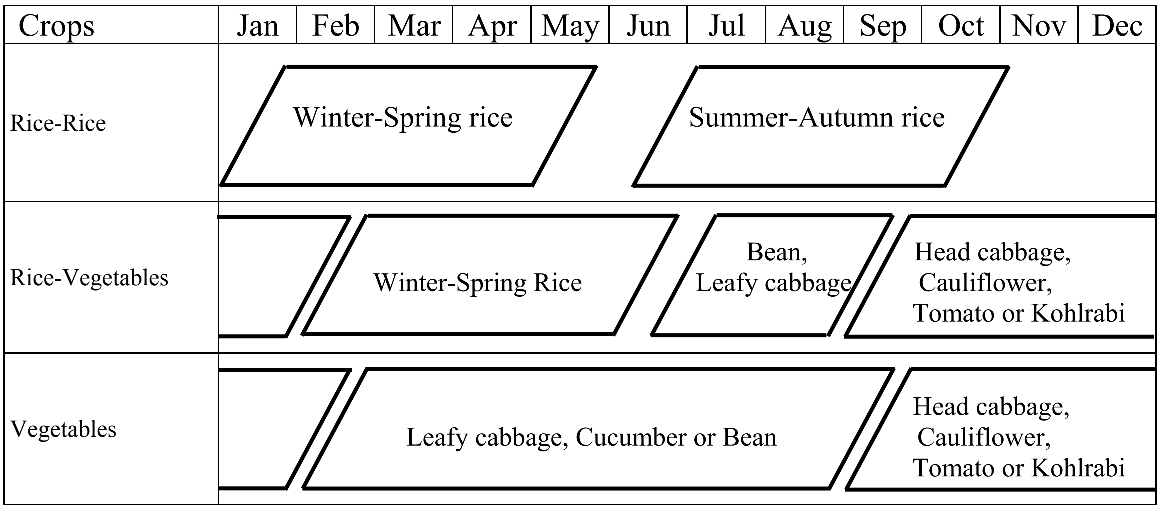

Figure 6.9. The cropping patterns in the urban area (Hadong district) (Synthesizing from household survey and group discussion, 2010)

In summary, the results from the survey of farmers in the study area show that farmers were prompt to change their crops from year to year according to price (last price, expected price and income) and their available investment capacity. Nevertheless, if farmers take an opportunity for increasing their incomes, they integrate market in their practice, and grow several crops at the same time.

6.2.1.2. Inputs used for vegetable production in different farming systems

The cost of labor inputs and the cost of fertilizer, pesticides and seeds are a large component of the overall costs of production. In addition, fees for irrigation can impose a considerable burden on producer margins.

6.2.1.2.1. Labor

As discussion in section 6.1.1.2, the most common type of labor used in the study area for agricultural purposes is family labor. The amount of labor and its cost varies across vegetables and between activities. The wages paid to laborers in the urban and peri-urban significantly higher than the rural area (65,000 VND/day and 100,000 VND/day, respectively). The most labor-intensive activities carried out for vegetable producers are irrigation, planting, weeding and harvesting.

6.2.1.2.2. Purchased inputs

The results indicate that seed costs are an important component of non-labor inputs for vegetables, with tomato, cabbage and cucumber seeds being the most expensive. Seeds are mainly purchased from village shops. Most of the seed sources do not provide authenticated and pure seed. Only a small percentage of farmers bought seed from input/output dealers who probably supply better quality seed. Therefore, improvement of the seed supply system can enhance the quality of seed available on the market and improve vegetable production.

Chemical fertilizer and pesticides are purchased from village shops that are private businesses not from state-owned enterprises. In contrast, organic fertilizer (manure) was obtained primarily from other farmers, and small amount from private business. General agricultural equipment was obtained mainly from private businesses.

6.2.2. Livestock production system

The livestock production is one of most important components of the farm production system in the study area. It is even more important, because livestock plays an important role in providing manure for vegetable production and soil fertility and sustainable agriculture. It is one of the income activities.

The main livestock kept by farmers are cattle, buffalo, pig and poultry (duck and chicken). The average cattle, buffalo, pig and poultry kept per farm-household in different area is presented in table 6.3.

Table 6.3. Livestock production in different farm household groups in the study area

Number of household kept	Rural	Peri-urban	Urban	Sig.
	N = 36	N = 33	N =33	
Cattle and buffalo	10	3	0	
Average	1.4	1		0.220
Pig	36	14	2	
Average	2.89	4.0	2.0	0.238
Poultry	36	21	6	
Average	39.17	63.81	11.67	0.293

(Synthesizing from household survey, 2009-2010)

The average number of pigs per farm-household is shown to be different among three areas. All farm-household in the rural area fed pig with an average was 2.9 heads. In the peri-urban area, 42% of farm-household fed pig, but in urban area just only 6% of farm-household fed big. The highest number of pig is in the peri-urban area with 4.0 head, and the lowest is in urban area with 2.0 heads. Raising Pig in the study area commonly required women's labor.

The highest number of farm-household owning cattle and buffalo is in the rural area with 27.78% with an average 1.4 heads. There is no farm-household fed cattle and buffalo in the urban area. This is because of non-availability of family labor to maintain livestock and limited in agricultural and grass land area in urban areas. In the peri-urban area, there were 9.1% of farm-household fed cattle and buffalo.

6.3. Synthesizing of sustainable indicators of vegetable cultivation systems in the study area

6.3.1. Financial analysis of vegetable production system

The equation 4.1 to 4.3 in chapter four are used to calculate gross revenue and gross margin and total variable costs per ha for all crops in the study area in order to understand the performance of the systems. Gross revenue is determined based on reported crop yield and farm gate price. Costs and returns are analyzed based on variable costs, including costs of human labor, animal power, seed, fertilizers, pesticides and insecticides, irrigation water, rent on power tillers and interest on operating capital. Costs of inputs are computed based on market prices, whether they were supplied from home or purchased. The results of financial analysis of the vegetable cultivation systems are represented in table 6.4, 6.5 and 6.6 for rural, peri-urban and urban area.

The financial analysis of vegetable cultivation systems for bean, headed cabbage, onion, cauliflower, tomatoes, sweet pepper, kohlrabi and cucumber in the rural area (MeLinh district) are represented in table 6.4. The results show that the highest gross revenue is belonging to the sweet pepper (243.89 million VND / ha), and the lowest value of gross revenue is cauliflower (20.1 million VND / ha). The gross margin value of all vegetable crops is higher than rice crop. The result reveals that the return to labor is highest in sweet pepper (36.1 million VND / ha), and the lowest is belonging to cauliflower (11.7 million VND / ha).

Referring to table 6.5, vegetable cultivation systems in the peri-urban area (ThanhTri district), and the cucumber crop offers the highest profit to farmers (12.9 million VND /

ha) and offers the highest return to labor (33.3 million VND / ha). Like the rural area, the lowest value of gross revenue is cauliflower (0.37 million VND / ha).

In the urban area (HaDong district), the result of financial analysis shows that the gross margin of the rice crop and kohlrabi crop give negative income to farmers (Table 6.6) caused by the higher price in hire labor and high input by using chemical fertilize (the price of organic fertilizer cheaper than chemical fertilizer), and the yields of those crops are lower than that in other regions.

Table 6.4. Financial analysis of vegetable cultivation systems in the rural area (MeLinh district)

Product/ Item	Unit	Rice	Bean	Headed cabbage	Onion	Cauli-flower	Leafy cabbage	Tomatoes	Sweet pepper	Kohlrabi	Cucumber
Aver.yield	kg/ha	4,740.14	12,761.90	33,278.24	19,709.30	13,952.02	22,002.92	48,605.66	20,324.07	24,829.37	22,407.41
Aver.price	VND	4,500.00	4,000.00	1,000.00	2,500.00	1,500.00	2,500.00	1,000.00	12,000.00	1,400.00	2,500.00
Costs:	1,000 VND/ha	19,911.87	41,057.22	24,359.27	26,618.48	19,319.41	23,878.29	41,894.80	56,152.78	21,894.44	34,729.63
Seed		3,631.91	1,880.95	1,473.83	1,703.55	1,164.14	2,500.00	3,611.11	1,944.44	2,326.19	1,361.11
Fertilizer		5,643.04	4,654.05	4,331.96	5,503.75	4,342.17	5,235.02	8,564.54	12,245.37	4,140.87	2,619.44
Plant protection		247.00	1,300.00	748.00	703.00	593.00	547.00	804.00	1,519.00	330.00	741.00
Labor		8,375.00	28,888.89	16,250.00	17,152.78	11,736.11	14,444.44	27,083.33	36,111.11	13,541.67	24,194.44
Other		2,014.92	4,333,33	1,655.48	1,555.40	1,483.99	1,151.83	1,831.82	4,332.86	1,555.71	5,813.64
Local input		13,918.40	33,119.84	16,780.30	18,603.04	12,733.59	16,834.80	25,890.52	22,106.48	14,690.48	22,166.67
Gr. revenue		21,330.65	51,047.62	33,278.24	49,273.26	20.928.03	61,220.76	48,605.66	243,888.90	34,761.11	56,018.52
Gr.margin		1,418.78	9,990.40	8,918.96	22,654.78	1,536.62	37,342.47	6,710.87	187,736.11	12,866.67	21,288.89

(Synthesizing from household survey, 2009-2010)

Table 6.5. Financial analysis of vegetable cultivation systems in peri-urban area (ThanhTri district)

Product/ Item	Unit	Rice	Bean	Headed cabbage	Cauli- flower	Leafy cabbage	Tomatoes	Kohlrabi	Cucumber	Water mor.glory
Aver.yield	kg/ha	4,552.55	12,646.75	33,644.58	14,642.86	24,282.41	46,925.93	24,682.54	20,879.63	19,857.14
Aver.price	VND	5,000.00	5,000.00	1,100.00	2,100.00	2,500.00	1,000.00	1,400.00	3,000.00	1,500.00
Costs:	1,000 VND/ha	19,398.40	53,905.53	36,469.71	30,380.16	36,739.58	43,062.22	31,511.62	49,712.96	27,093.73
Seed		5,348.11	2,468.55	1,967.87	2,094.44	3,947.92	1,528.89	3,496.60	1,736.11	1,944.44
Fertilizer		4,397.85	8,492.53	2,424.20	6,202.38	8,226.85	7,748.15	8,177.72	8,939.82	7,694.92
Plant protection		139.00	1,423.48	963.86	416.67	457.18	907.41	948.41	703.70	126.98
Labor		8,114.40	40,618.45	25,000.00	19,444.44	22,232.12	27,777.78	17,546.67	33.334.34	13,888.89
Other		1,399.04	902.52	6,113.78	2,222.23	1,875.51	5.099.99	1,342.22	4,998.99	3,438.50
Local input		7,743.57	41,281.97	27,069.62	22,301.59	24,513.89	31,644.44	18,816.33	33.334.34	14,091.75
Gr. revenue		22,762.73	63,233.75	37,009.04	30,750.00	60,706.02	46,925.93	34,555.56	62,638.89	29,785.71
Gr.margin		3,364.33	9,328.22	574.47	369.84	23,966.44	3,863.70	3,043.93	12,925.93	2,691.98

(Synthesizing from household survey, 2009-2010)

Table 6.6. Financial analysis of vegetable cultivation systems in urban area (HaDong district)

Product/ Item	Unit	Rice	Bean	Headed cabbage	Cauliflower	Leafy cabbage	Tomatoes	Kohlrabi	Cucumber
Aver.yield	kg/ha	4,386.94	11,629.40	29,439.89	11,843.43	21,079.06	40,421.46	21,095.01	18,151.34
Aver.price	VND	5,000.00	5,000.00	1,400.00	3,000.00	2,600.00	1,500.00	1,600.00	3,000.00
Costs:	1,000 VND/ha	25,521.48	52,902.10	40,693.53	35,128.79	41,238.12	59,098.66	34,578.16	49,985.63
Seed		6,360.68	3,321.14	2,216.53	2,159.09	5,000.00	2,138.89	4,180.56	2,083.33
Fertilizer		9,337.89	9,576.90	9,394.35	10,681.82	11,400.64	11,597.70	10,388.89	10,127.39
Plant protection		222.00	1,406.50	1,104.51	343.44	685.90	1,195.40	935.59	1,356.32
Labor		8,333.33	33,319.78	25,478.14	19,300.44	22,132.20	38,888.89	16,666.67	33,433.34
Other		1,267.58	5,277.78	2,500.00	2,644.00	2,019.38	5,267.78	2,406.45	2,985.25
Local input		6,812.07	33,319.78	25,113.84	19,444.94	22,132.20	38,888.89	16,723.03	33,433.34
Gr. revenue		21,934.68	58,147.02	41,215.85	35,530.30	54,805.56	60,632.18	33,752.01	54,454.02
Gr.margin		-3,586.81	5,244.92	563.30	404.04	13,522.44	1,533.53	-835.15	4,468.39

(Synthesizing from household survey, 2009-2010)

6.3.2 Market channel trend

Efficient of market channel based on the stability of the market by constructing an index based on farmer's subjective judgment to a question related to the market trend. The vegetable growers are asked about the trend of market such as: increasing or decreasing or maintain market.

In the study area, farmers either transport their products to one of the wholesale markets, or collectors come to their farms and purchase products for the sellers in the wholesale market are common ways. There are little direct sales from farmers to consumers in the local market. Virtually, nothing is sold at the factory level. The form of transport to buy and sell vegetables in the study area is simple by motorcycles, bicycles (Figure 6.11).

Figure 6.10. Wholesale market in the rural area (Melinh district)

Figure 6.11. Farmers were carrying vegetable in the rural area (MeLinh district)

The market channel trend surveys results are presented in figure 6.12, the majority of the responses in maintain market with 73% is belonging to the urban area, 64% in the rural area and 46% in the peri-urban area. The highest responses in increasing market is belonging to the peri-urban area (55%) and 36% in the rural area and then 12% in the urban area, respectively. Fifteen percent of the respondents in the urban area have confirmed in decreasing market channel in the last five years.

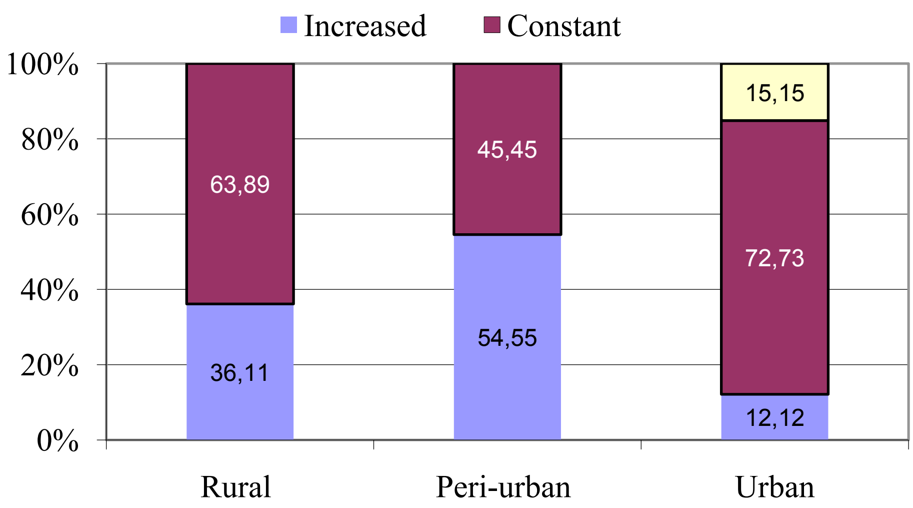

Figure 6.12. Market channel trend in the rural area (MeLinh district)

6.3.3. Yield stability

In this study yield stability are measured by the index of trend of yield. Yield trend is estimated base on the stability of crop yield by constructing an index based on farmer's subjective judgment to a question related to yield trend.

The survey results show that the number of respondents is highest in the peri-urban area with 64%, following by 61% in rural areas, and finally urban areas with a response rates is lowest with 36%. The survey results also show that 33% respondents in the rural areas, 27% in the peri-urban and 15% in the urban areas confirmed in increasing yields in the last 5 years, respectively. But in urban areas, 48% of respondents confirmed in decreasing of vegetable's productivity (Figure 6.13).

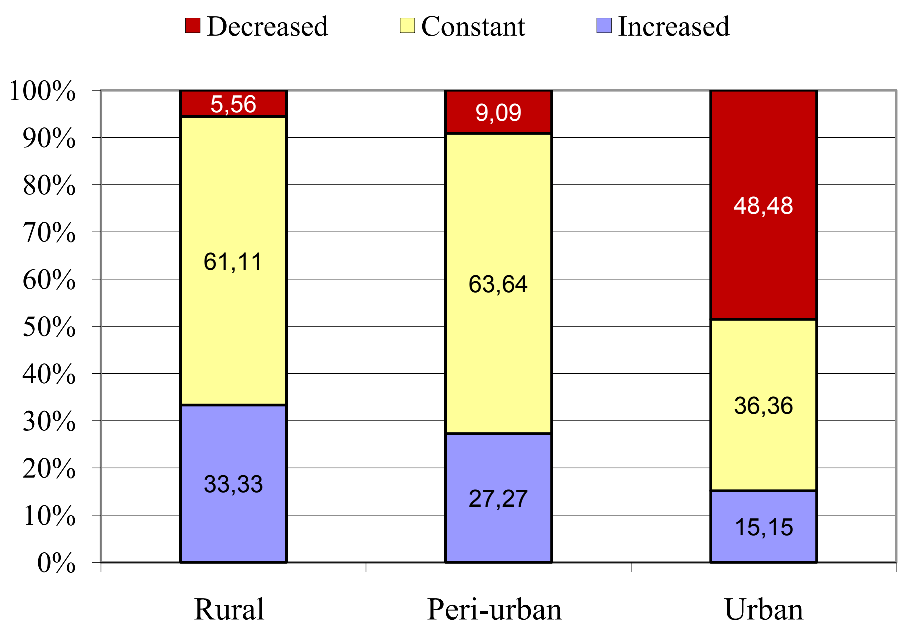

Figure 6.13. Vegetable yield trend in the study area

6.3.4. Input self sufficiency

Input self sufficiency is determined base on the ratio of local input costs to the total input costs. The higher local inputs mean higher input self sufficiency. There is considerable variation between the systems in terms of dependency on external inputs. In the urban vegetable cultivation system, there is a tendency to use external inputs, notably chemical fertilizers, pesticides, diesel, irrigation water and hired machine accounting for 45% of the total input cost greater than in Peri-urban (40%) and rural area (22%), respectively (Table 6.7). The high dependency on external inputs increases farmer's vulnerability to reduce profit.

Table 6.7. The average of total input and local input costs in the study area (1,000 VND)

	Rural area	Peri-urban area	Urban area
Average total input cost	25,104.48	49,023.13	38,553.88
Average local input cost	19,597.67	29,582.39	21,119.72
Index of input self sufficiency	0.78	0.60	0.55

(Synthesizing from household survey, 2009-2010)

6.3.5. Employment

In the study area, family labors are mainly used, and hire labors are minor uses for planting, taking care and harvesting of vegetables without any machines support (Figure 6.14).

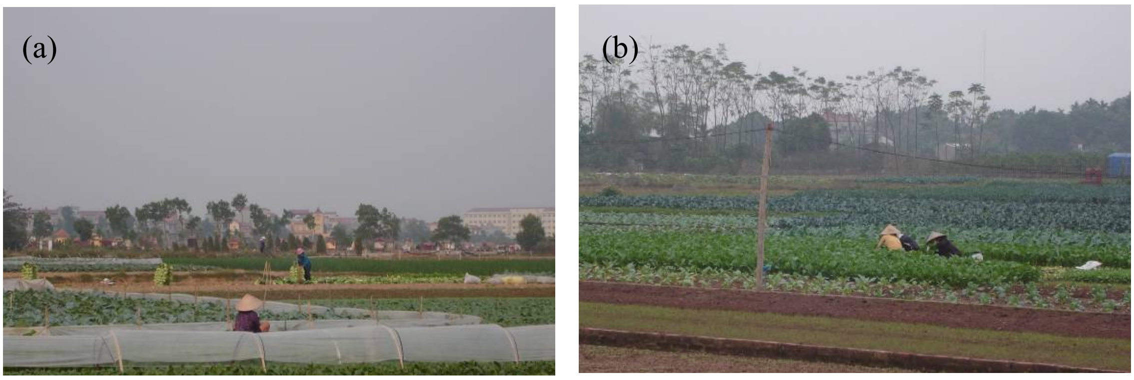

Figure 6.14. Farmers were harvesting vegetable (a) in ThanhTri and (b) in MeLinh district

The survey results show that labors trend involved in vegetable cultivation in last five years increased account for 47% of the respondents to compare with 17% of respondents confirmed in decreasing labor used in the rural area, whereas the number of labors trend involved in their vegetable farms decreased rapidly account for 64% of the respondents, and 3% of the respondents verified in increasing labor used in the urban area (Figure 6.15). The reasons are that people whose live in the urban areas are no longer keen on growing vegetables caused by low-income, hard work, as well as vegetable growers used herbicides to reduce the cost of taking care their vegetable farm and higher profit.

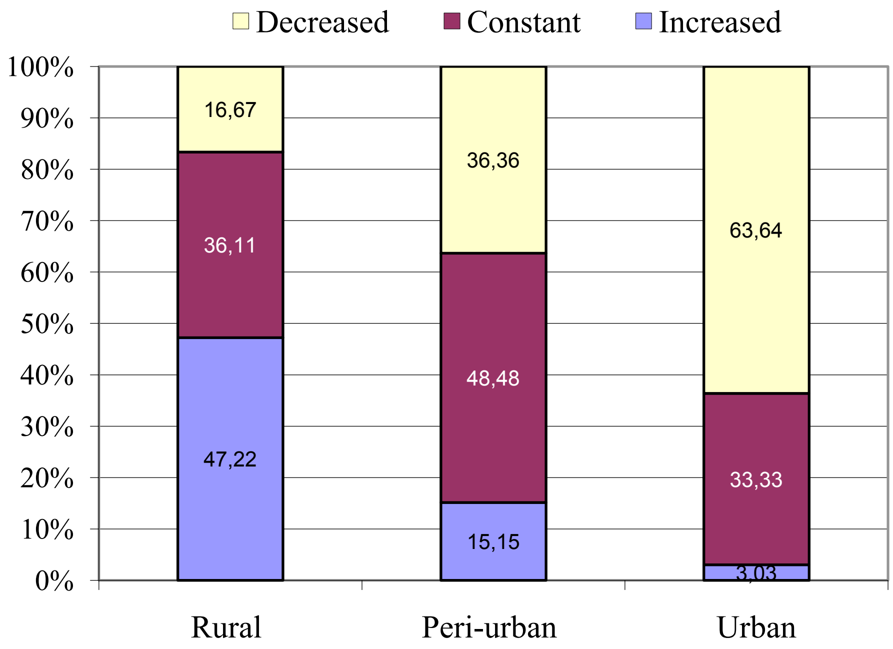

Figure 6.15. Labors involved in vegetable cultivation trend in the study area

6.3.6. Access to agricultural extension services

The survey results are presented in figure 6.16. The results show the percent of respondents that they had received some kind of extension service over the previous year, but this varied significantly between regions. Vegetable growers in the rural area are much more likely to receive extension services (58%) than those in the peri-urban (48%) and the urban (18%). Extension services are provided by Extension Services Department and by the Farmer's Union. In terms of the type of service provided to vegetable growers relating to fertilizer use and pest management are the most common forms of extension provided, the advice about selection of the vegetable variety and irrigation techniques and some producers interested in information about marketing.

Results from surveyed also indicate surprisingly that the vegetable grower in the urban areas has limitation access to agricultural extension than vegetable growers in the peri-urban and in the rural areas. This is because farmers could access to other information sources such as internet, television, so they are not interested and needed the advice from the extension center. A small number of farmers mentioned that they actively experiment with different growing techniques and fertilizer, pesticide application. However, many farmers mentioned that they just followed the recommendations from instruction printed in the containers.

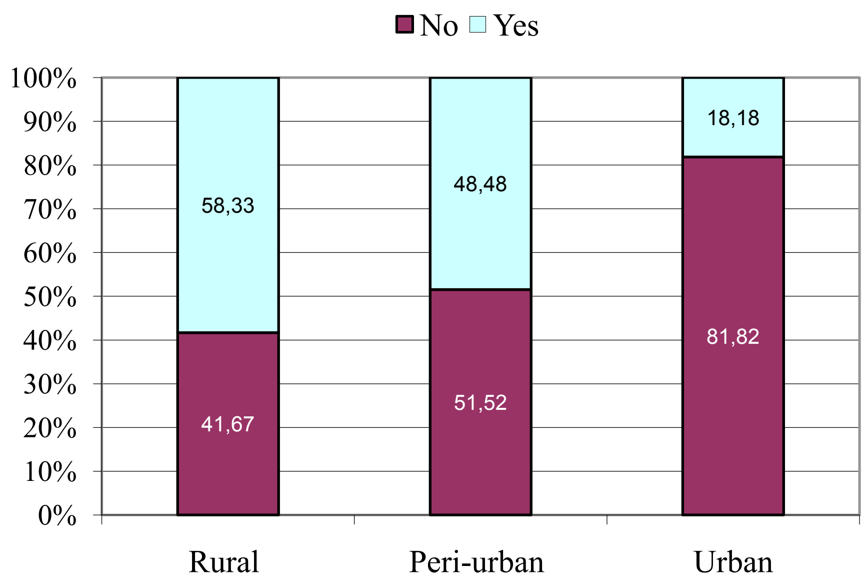

Figure 6.16. Access to agricultural extension services

6.3.7. Access to credit

The result from the survey shows that percent of producers in the study area used credit to fund their agricultural activities. 100% of respondents confirmed that they accessed to the credit. 28% and 12% of farmers in the rural area and in the peri-urban area did not access to the credit (Figure 6.17). The credit obtained from friends, relatives and traders are the highest levels of credit obtained. The main reason given for not being able to access funds is that credit applicants had difficulties dealing with the bank (or credit institution) and the interest rate is high.

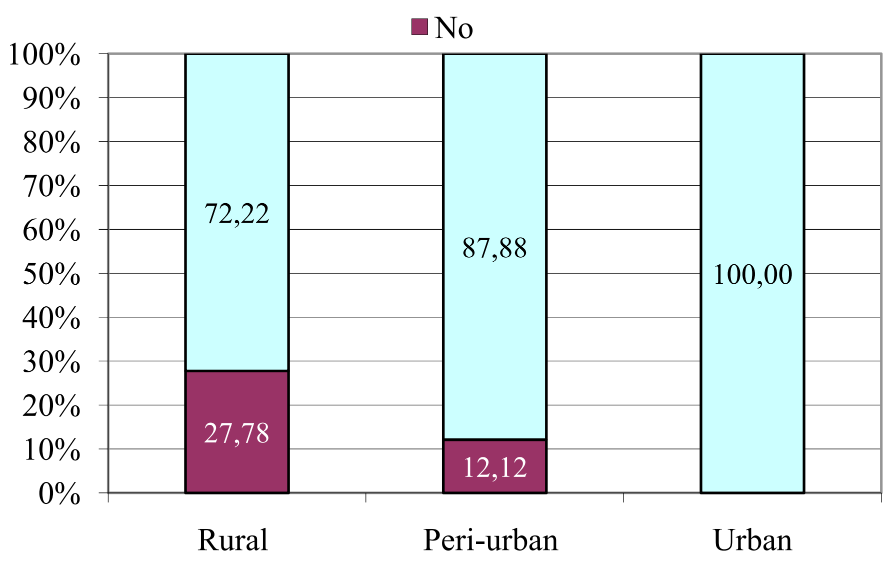

Figure 6.17. Access to credits in the study area

6.3.8. Soil managment

Farmers are asked about their fertilizer used when growing vegetables and how this has changed over the past five years. Most of farmers in the study area applied two main types of fertilizers to their farmlands. These are organic fertilizers and inorganic fertilizers. The organic fertilizers that farmers used include composted livestock and pig manure with rice straw. The main types of inorganic or chemical fertilizers used by farmers include urea, potassium chloride (KCl), and compound fertilizers containing various quantities of nitrogen, phosphorous and potassium (NPK). Some farmers also applied lime as a soil amendment to regulate the pH of the soil. Discussion with farmers also revealed that farmers have applied increasingly amounts of chemical fertilizers over successive years to maintain yields because of gradual deterioration of soil quality caused by not good intercropping and overuse of chemical fertilizers.

6.3.8.1. Use of organic fertilizer

The results from the survey (Figure 6.18) show that 64% and 48% of respondents in the urban and in the peri-urban areas confirmed in decreasing of organic fertilizer applied, whereas in the rural area 83% of respondents verified that the organic fertilizer applied in last five years still maintained. Limited availability of animal manure in the peri-urban and in the urban area contributed to these results.

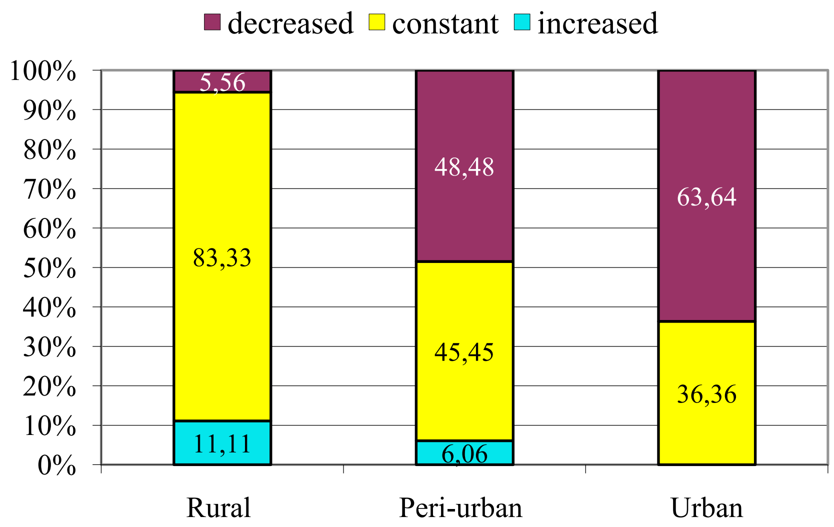

Figure 6.18. Use of organic fertilizer trend in the study area

Figure 6.19. Compost manures were placed on the lane in the field (MeLinh district)

Overall, per ha application of manure is different between the urban and the peri-urban and the rural area. The farmers in the urban and in the peri-urban met the deficiency in manure for their crops. The compound fertilizers containing various quantities of nitrogen, phosphorous and potassium (NPK) is used, and chicken manure is most commonly used in the urban regions. On the other hand, the rural and the peri-urban farmers mainly used pig manure and compound fertilizers (Figure 6.19). Most of the available manure in the urban and in the peri-urban area is applied to vegetables, but in the rural area other crops receive almost the same amount of manure as vegetables.

6.3.8.2. Use of chemical fertilizers

The use of chemical fertilizer trend is an indicator of soil fertility management. The use of chemical fertilizer trend in the study areas is obtained. All farmers applied chemical fertilizers to their vegetable farms.

The survey results (Figure 6.20) show minor percentage of the farmers in the rural area (8%) confirmed that they now use less chemical fertilizer compared to five years ago. 73%, 72%, and 45% of farmers in the peri-urban, in the rural and in the urban areas reported that they used the same amount of chemical fertilizer now compared to five years ago, and the remainder reported that they used of chemical fertilizer increasing over the past five years such as 19%, 27% and 55% in the rural, in the peri-urban and in the urban area, respectively.

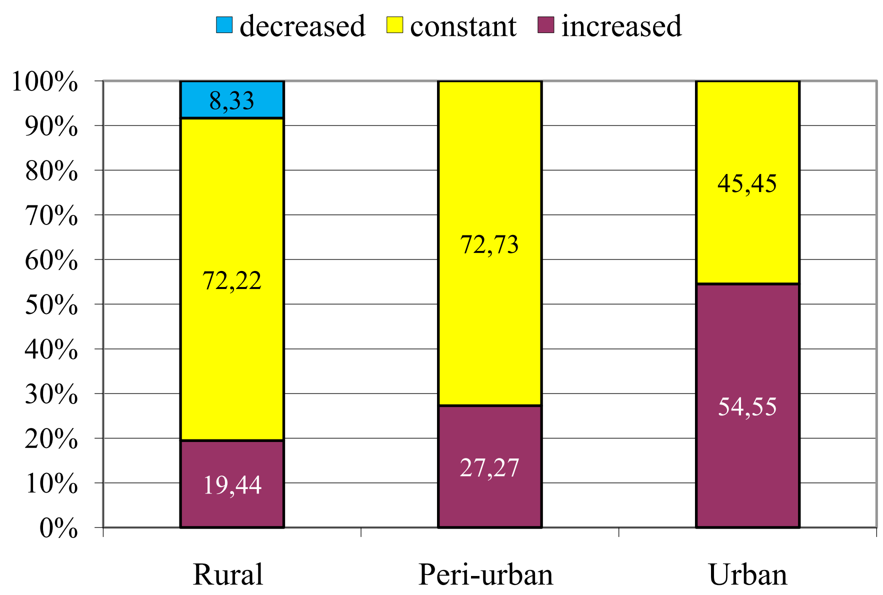

Figure 6.20. Use of chemical fertilizer trend

6.3.8.3. Cultivation of legume crops

Legumes are utilized in agriculture because they enhance the productivity and potential sustainability of farming systems. In the study area, most of the farmers grew soybean and beans as intercropping with other crops for soil fertility management and for cash.

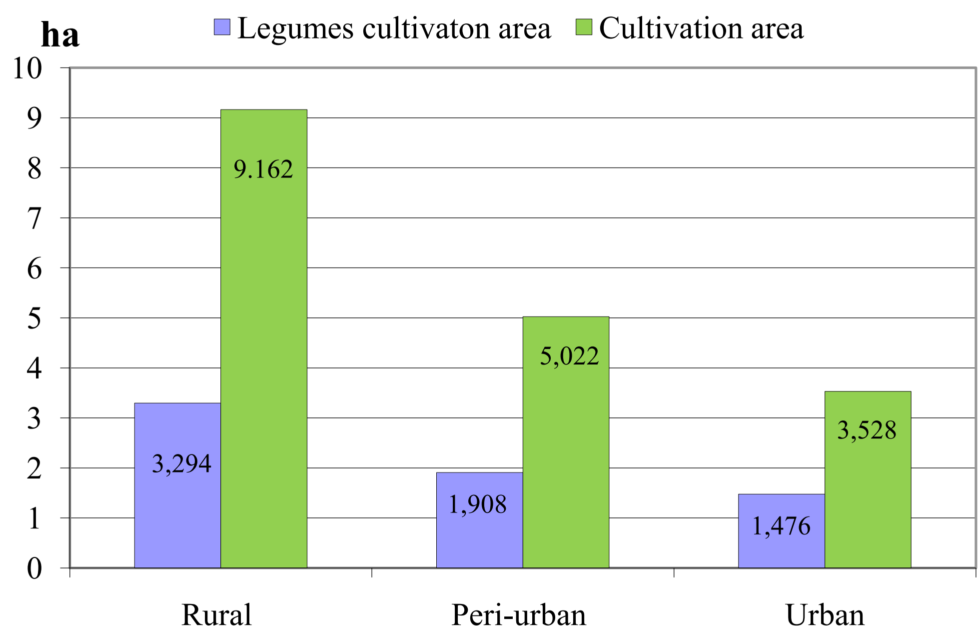

Figure 6.21. Total cultivation area and legumes cultivation area

Moreover, residue from legumes can be used as fodder for farm animals. The highest legumes cultivation area is 3.294 ha in the rural area, and the lowest legumes cultivation is 1.476 ha in the urban area (Figure 6.21). However, the proportion of legumes crop is highest in the urban area, account for 42% of total cultivation area and then in the urban area with 38%, and the lowest is in the rural area 36%, respectively.

6.3.9. Human health status

Most farmers did not follow the advice of extension workers in pesticide application. Their practices may harm their health as well as those of the consumers. Some farmers did not respect the recommended pre-harvest interval, which could affect vegetable consumers' health. Other reported that they did not wear any protective clothing or wear masks to cover nose and mouth while spraying pesticides and insecticides (Figure 6.22). As a result, the percent of farmers getting ill is proportional to higher frequency of pesticide applications.

Farmers were asked to give their opinions about the health status of their family members, and the frequency that they got ill whether increasing or decreasing in the last five year caused by diseases that related to their living environment, by chemicals used in agriculture or food poisoning (including: skin irritation, dizziness, cough, ‘soggy eyes’ (excessive tearing), numbness, severe headaches, ‘motion sickness’ (nausea or giddiness), tremors, vomiting and chest pain). The results show that the highest respondents confirmed that the health status’s trend of their family members has improved in the rural area with 53%, the lowest is belonging to the peri-urban area with 33%.

Figure 6.22. Farmers were spraying pesticides without any protective clothing (a) in MeLinh and (b) in Hadong district.

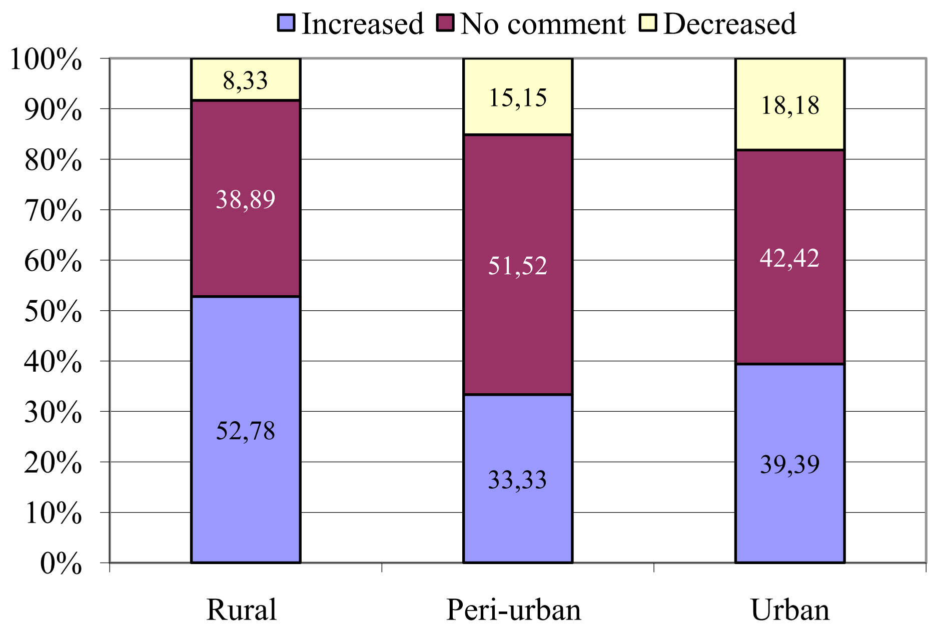

Figure 6.23. Human health trend in the study area

The survey results also show minor percentage of the respondents that the trend of their family member's health status has decreased with 18%, 15% and 8% in the urban, in the peri-urban and in the rural area, respectively (Figure 6.23). There trend caused by water pollution, air pollution due to the use of chemical control of their plants, industrialization and urbanization process.

6.3.10. Management of pests and diseases

The use of too much urea is not sustainable in the long term; too much nitrogen applies for crops also enhance plant growth that attracts some insect pests. Thus, this could be a source of increasing in pesticide use. All the farmers in the study area reported that they applied pesticides on their vegetables. Farmers were asked whether they are using more or less pesticides now than they were in five years ago.

A majority (55-70%) of the farmers in the study area reported that they used the same amount in the last five year. 36% of farmers in peri-urban mentioned that they increasingly used of pesticides than five years ago (Figure 6.24). They sprayed insecticides periodically even if they do not find any insect symptoms. The reason given for this increase in pesticide used that they are afraid their vegetables would be sold at low price because of insect symptoms.

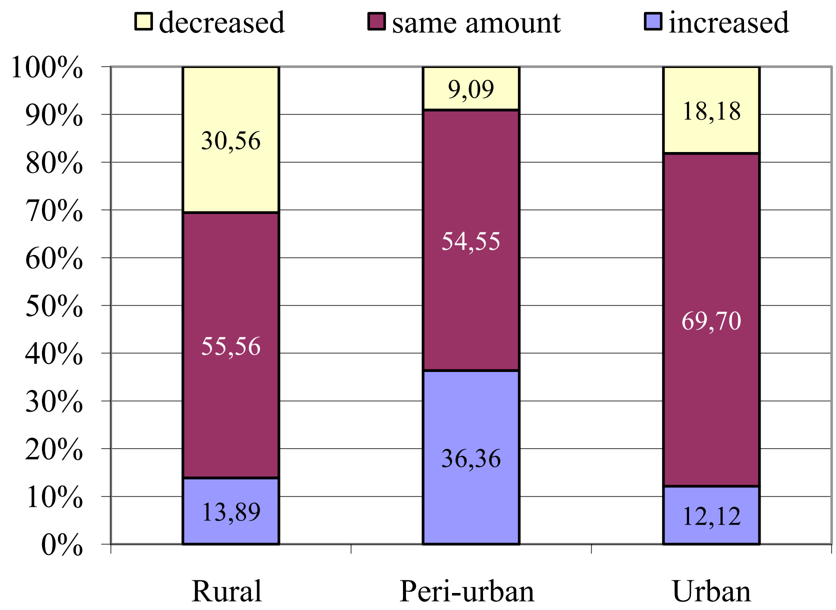

Figure 6.24. Use of chemical control trend in the study area

Most farmers confirmed that they have sprayed insecticides five to ten times during one vegetable season. At seedbed preparation, insecticides are usually applied at least one time. During the vegetative development stage, farmers spray insecticides every four to five days. At establishing economic organ of cabbage, farmers applied insecticide every two to three days (Figure 6.25).

Figure 6.25. The overused of pesticide's remnants in head cabbage in the peri-urban area (Thanh Tri district)

6.3.11. Irrigation systems in the study area

In the study area, the producers have access to either mechanical irrigation or canal irrigation. The type of irrigation used on specific crops varies between regions. According to farmers in the peri-urban area, the water in To Lich River is used as the main source of irrigation water for vegetable. The To Lich River starts from West Lake in the northern part of Hanoi and runs down to the south of the city with wastewater from domestic use, industries and hospitals. This wastewater water is considered with high contaminated 'chemicals' that might damage skin and health risks associated with farming and pest attacks to vegetable due to 'bad quality of irrigation water'. In the urban area, the producers have to hire well drilling to make the wells in order to access to groundwater (Figure 6.26), and water is often pumped for irrigating their vegetables. In the rural area, most producers accessed to canal irrigation (Figure 6.26). Some farmers used pump to take water from canal for watering their farms, some took water and watering by hand.


Figure 6.26. Simple irrigation technique in the study area

6.4. Weight computation

As mention in chapter 4, the weighing factors have been derived using pairwise comparison method. Three workshops were organized to define the score weight of each factor. The number of participants is thirteen people, including one agricultural extension, and twelve farmers (four farmers in each commune) who were selected by using simple random techniques. After debated and careful analyzed of the set of evaluation criteria, the criterion weights were calculated (Appendix a-1to a-3), and represented in table 6.8, table 6.9 and table 6.10.

Table 6.8. The weight factors of all indicators in the rural area (Me Linh district)

Ecological indicators		Economic indicators		Social indicators		Overall sustainability	
UCF	0.09	FR	0.25	ISS	0.12	ECONsus	0.65
UOF	0.45	YIT	0.16	EPL	0.26	SOCsus	0.12
CLC	0.22	EMC	0.59	AC	0.45	ECOLsus	0.23
UCC	0.06			AAE	0.17		
HH	0.17						

(Synthesizing from stakeholder workshop, 2009) (legends see figure 5.1)

Table 6.9. The weight factors of all indicators in the peri-urban area (Thanh Tri district)

Ecological indicators		Economic indicators		Social indicators		Overall sustainability	
UCF	0.05	FR	0.30	ISS	0.12	ECONsus	0.33
UOF	0.23	YIT	0.54	EPL	0.40	SOCsus	0.14
CLC	0.34	EMC	0.16	AC	0.11	ECOLsus	0.52
UCC	0.07			AAE	0.37		
HH	0.31						

(Synthesizing from stakeholder workshop, 2010) (legends see figure 5.1)

Table 6.10. The weight factors of all indicators in the urban area (Ha Dong district)

Ecological indicators		Economic indicators		Social indicators		Overall sustainability	
UCF	0.05	FR	0.39	ISS	0.12	ECONsus	0.17
UOF	0.31	YIT	0.44	EPL	0.47	SOCsus	0.39
CLC	0.37	EMC	0.17	AC	0.12	ECOLsus	0.44
UCC	0.07			AAE	0.30		
HH	0.20						

(Synthesizing from stakeholder workshop 2010) (legends see figure 5.1)

6.5. Fuzzy rules determination

Workshop was carried out in February 2010; total 476 rules were gathered based on twelve indicators. The number of participants is thirteen people, including one agricultural extension, and twelve farmers who were selected by using simple random techniques (four farmers in each region who were selected from four farmers in each commune). The agricultural extension gave the rule, and all participants involved in the decision-making process to give the decision in each rule (Table 6.11 and Appendix b-1 to b-4).

Table 6.11. Example of the rule application for environmental sustainability assessment

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
1	Low	Low	Low	Low	Low	Vbad
2	Low	Low	Low	Low	Medium	Vbad
85	Medium	Low	Low	Medium	Low	Bad
143	Medium	High	Low	High	Medium	Satisfactory
164	High	Low	Low	Low	Medium	Bad
243	High	High	High	High	High	Vgood

(Synthesizing from stakeholder workshop, 2010) (legends see figure 5.1)

6.6. Resume of main finding

The results of data collection on different vegetable cultivation systems show that the farms in those communes are small-scale vegetable and/or mixed vegetable-rice farms. The vegetable species are cultivated in the study area, e.g. indigenous vegetables as cucumber, leafy cabbage, soy bean, bean (such as yard long bean, green bean…) and water morning glory and non-indigenous vegetables as headed cabbage, cauliflower, kohlrabi, leafy cabbage, sweet pepper and tomato. Agricultural land in study area has decreased notably due to urbanization and industrialization, e.g. for residences, business, industrial parks and public works. Following the investigations majority of the labor force in the study area has employment, the number of unemployed accounts for only a small share. The most common type of labor used in the study area for agricultural purposes was family labor. Wages average VND 65 thousand per day in the rural area, VND 100 thousand per day in the peri-urban and urban area. Most vegetable producers in study area started growing vegetables since 1986. An average household head experience in growing vegetables was 15 years to 20 years. The main livestock kept by farmers were cattle, buffalo, pig and poultry (duck and chicken). The cattle, buffalo, pig and poultry kept per farm-household in different regions with the highest in the rural area. There was no farm-household fed cattle and buffalo in urban area. The trend of organic fertilizer usage declined, and the trend of chemical fertilizer usage increased caused by the limited availability of animal manure in the study areas. Parallel with this farmer's usage of pesticide increased and applied in unsustainable manners, farmer's concern just is the income from their farm and has limitation access agricultural extension service.

The financial analysis results of vegetable cultivation systems in the study area revealed that the gross margin value of all vegetable crops is higher than rice crops and the return to labor in all vegetable crops is higher than rice crops this is an evidence to confirm that vegetable production provides more jobs “vegetables are labor-intensive crops” (JUSTIN *et al.* 2009) compared to cereal production. The yield of almost vegetable crops and rice crops in the rural area are higher than other regions in the study area. The average total input costs in the urban and peri-urban more higher than the rural vegetable cultivation system, but the self-sufficiency in the rural are higher. The use of external inputs, notably chemical fertilizers, pesticides, diesel, hired machine and also the wage to pay to labor is higher than the rural vegetable cultivation system. Therefore, the gross margin of the rural vegetable cultivation system is much higher than the peri-urban and urban vegetable cultivation systems.

7. SUSTAINABILITY ASSESSMENT

This chapter presents the sustainability assessment results by using three methods such as sustainability assessment by multicriteria methods with the indicators are equal and unequal importance, and sustainability assessment by fuzzy evaluation method and also the sensitive analysis and discussion on the finding are presented.

7.1. Normalization of indicators

Instead of using the raw data for each indicator directly, the data were normalized to obtain a common scale and allow statistical aggregation. Normalized values are constructed in 0 to 1 scale and the higher the value, the better sustainability. The equation 5.5 to equation 5.9 in chapter 5 was used to normalize all indicators.

The target value of all indicators was set following:

The indicators such as yield trend, market channel trend, labors trend involved, chemical fertilizers used trend, organic fertilizers used trend and community health status trend were estimated based on farmer's subjective judgment, and the index was calculated based on the equation 5.4 in chapter four and range from -1 to +1.

The input self sufficiency indicator was determined base on the ratio of local input costs to the total input costs. The higher local inputs mean higher input self sufficiency. The expected target value is +1.

The average area cultivates legume crops in cropping systems are considered to compare the sustainability between cropping systems. The target value expected is +1 that means all area could be grown rotation the legume crops with the others.

To encourage the development of farm economy, the Central Economic Committee, Ministry of Agriculture and Rural Development, and Vietnam Farmers Association have launched programs: "The field with 50 million per ha and income reaches to 50 million VND per household" (MAAD 2003). In 2006, the average gross revenue of agricultural land reached around 17 million VND/ha (KIEN 2006). Therefore, targets 50 million/year/ha of agricultural land is the common striving. In this study, the target value of gross revenue is set at 50 million VND/ha/year.

The normalized values can be observed in table 7.1 for the rural area, table 7.2 for the peri-urban area and table 7.3 for the urban area.

Table 7.1. Normalization of criteria/ indicators for vegetable cultivation systems in the rural area (Me Linh district)

Indic.	**Unit**	**min(s)**	**max(s)**	**T(v)**	**data(v)**	**I(v)**
FR	Million dong/ha	0	max	50	36.24	**0.72**
IYT	Index (yield trend)	-1	+1	max(s)	0.28	**0.64**
EMC	Index (market channel trend)	-1	+1	max(s)	0.36	**0.68**
ISS	Index (ratio of local inputs cost to the total inputs cost)	0	1	max(s)	0.78	**0.78**
EPL	Index (labor involved trend)	-1	+1	max(s)	0.31	**0.65**
AC	Index (yes, no statement)	0	0.5	max(s)	0.36	**0.36**
AAE	Index (yes, no statement)	0	0.5	max(s)	0.29	**0.29**
UCF	Index (use of chemical fertilizers trend)	-1	+1	min(s)	0.11	**0.44**
UOF	Index (use of organic fertilizers trend)	-1	+1	max(s)	0.56	**0.53**
CLC	Index (ratio of legume crops area/total cultivation area)	0	9,162	max(s)	3,294	**0.36**
UCC	Index (use of chemical control trend)	-1	+1	min(s)	0.17	**0.58**
HH	Index (community health status trend)	-1	+1	max(s)	0.44	**0.72**

Note: min(v) = minimum values, max(v) = maximum values T(v) = target values, data(v) = data values, I(*v*) = normalized value
(Analyzing from household survey, 2009-2010, legends see figure 5.1)

The results of normalized values in table 7.1, table 7.2 and table 7.3 shows that the normalized value of UCF, UOF, and UCC is low. The results revealed that farmers' usage of chemical fertilizers and usage of chemical control increased in order to obtain the highest in yield. Therefore, the normalized of the economic sustainability is high with the value 0.72, 1.0 and 0.8 in the rural area, peri-urban area and in the urban area, respectively.

Table 7.2. Normalization of criteria/ indicators for vegetable cultivation systems in the peri-urban area (Thanh Tri district)

Indic.	Unit	min(s)	max(s)	T(v)	data(v)	I(v)
FR	Million dong/ha	0	max	50	55.87	**1.00**
IYT	Index (yield trend)	-1	+1	max(s)	0.18	**0.59**
EMC	Index (market channel trend)	-1	+1	max(s)	0.55	**0.77**
ISS	Index (ratio of local inputs cost to the total inputs cost)	0	1	max(s)	0.60	**0.60**
EPL	Index (labor involved trend)	-1	+1	max(s)	-0.21	**0.39**
AC	Index (yes, no statement)	0	0.5	max(s)	0.44	**0.44**
AAE	Index (yes, no statement)	0	0.5	max(s)	0.24	**0.24**
UCF	Index (use of chemical fertilizers trend)	-1	+1	min(s)	0.27	**0.36**
UOF	Index (use of organic fertilizers trend)	-1	+1	max(s)	-0.42	**0.29**
CLC	Index (ratio of legume crops area/total cultivation area)	0	5,022	max(s)	1,908	**0.38**
UCC	Index (use of chemical control trend)	-1	+1	min(s)	-0.27	**0.36**
HH	Index (community health status trend)	-1	+1	max(s)	0.18	**0.59**

Note: min(v) = minimum values, max(v) = maximum values T(v) = target values, , data(v) = data values, I(*v*) = normalized value
(Analyzing from household survey, 2009-2010, legends see figure 5.1)

The normalized values of the market trend are highest in the peri-urban area (0.77) and the lowest in the urban area (0.48). In the aspect of ecological sustainability, the normalized value of farmers' usage of organic fertilizers is low caused by declined in the number of animal kept. In all vegetable systems, farmers' cultivations of legumes for soil fertility improvement with the normalized are 0.42 in the urban area, 0.38 in the peri-urban area and 0.36 in the rural area. The lowest normalized value in the urban area (0.09) is belonging to the AAE indicator caused by 82% of the farmer did not access to agricultural extension services.

Table 7.3. Normalization of criteria/ indicators for vegetable cultivation systems in the urban area (Ha Dong district)

Indic.	**Unit**	**min(s)**	**max(s)**	**T(v)**	**data(v)**	**I(v)**
FR	Million dong/ha	0	max	50	40.21	**0.80**
IYT	Index (yield trend)	-1	+1	max(s)	-0.33	**0.33**
EMC	Index (market channel trend)	-1	+1	max(s)	-0.03	**0.48**
ISS	Index (ratio of local inputs cost to the total inputs cost)	0	1	max(s)	0.55	**0.55**
EPL	Index (labor involved trend)	-1	+1	max(s)	-0.61	**0.20**
AC	Index (yes, no statement)	0	0.5	max(s)	0.50	**0.50**
AAE	Index (yes, no statement)	0	0.5	max(s)	0.09	**0.09**
UCF	Index (use of chemical fertilizers trend)	-1	+1	min(s)	0.55	**0.23**
UOF	Index (use of organic fertilizers trend)	-1	+1	max(s)	-0.64	**0.18**
CLC	Index (ratio of legume crops area/total cultivation area)	0	3,528	max(s)	1,476	**0.42**
UCC	Index (use of chemical control trend)	-1	+1	min(s)	0.06	**0.53**
HH	Index (community health status trend)	-1	+1	max(s)	0.21	**0.61**

Note: min(v) = minimum values, max(v) = maximum values T(v) = target values, data(v) = data values, I(*v*) = normalized value
(Analyzing from household survey, 2009-2010, legends see figure 5.1)

7.2. Results of sustainability assessment by multicriteria evaluation methods

7.2.1. Sustainability assessment by multicriteria evaluation method where indicators are equal importance

After normalization of the data, aggregation method in section 5.3.1.1 was used to get the aggregate value for each indicator. In this calculation, W_i represents the weight of each indicator and the calculation of weights are based on the reference that components of sustainability should be given identical weight in an overall sustainability assessment (IUCN/IDRC 1995). So, equal weights (0.333) for ecological, economic and social sustainability are assigned and divided equally for secondary indicators as follows.

Table 7.4. The weights (Wi) assigned for each indicator in overall sustainability (Indicators are equal importance)

Components of sustainability	Weights (Wi)	Indicators	Weights (Wi)
Ecological sustainability	0.333	UCF	0.067
		UOF	0.067
		CLC	0.067
		UCC	0.067
		HH	0.067
Economical sustainability	0.333	FR	0.111
		IYT	0.111
		EMC	0.111
Social sustainability	0.333	ISS	0.083
		EPL	0.083
		AC	0.083
		AAE	0.083

(legends see figure 5.1)

According to calculation, 0.067 for ecological sustainability indicators (UCF, UOF, CLC, UCC and HH) are assigned for aggregation, 0.111 for economic sustainability indicators (FR, IYT and EMC) and 0.083 for social sustainability indicators (ISS, EPL, AC, AAE) are assigned as weights in aggregation (Table 7.4). The aggregations results of sustainability in muticriteria evaluation method with indicators are equal importance are represented in table 7.5.

Table 7.5. The results of sustainability in muticriteria evaluation method (Indicators are equal importance)

Indicators	Wi	Rural area		Puri-urban area		Urban area	
		I_i	W_i*I_i	I_i	W_i*I_i	I_i	W_i*I_i
UCF	0.067	0.44	0.029	0.36	0.024	0.230	0.015
UOF	0.067	0.53	0.035	0.29	0.019	0.180	0.012
CLC	0.067	0.36	0.024	0.38	0.025	0.420	0.028
UCC	0.067	0.58	0.039	0.36	0.024	0.530	0.035
HH	0.067	0.72	0.048	0.59	0.039	0.610	0.041
Ecol sus	0.333		**0.18**		**0.13**		**0.13**
FR	0.111	0.72	0.080	1.00	0.111	0.800	0.089
IYT	0.111	0.64	0.071	0.59	0.065	0.330	0.037
EMC	0.111	0.68	0.075	0.77	0.085	0.480	0.053
Econ sus	0.333		**0.23**		**0.26**		**0.18**
ISS	0.083	0.78	0.065	0.6	0.050	0.550	0.046
EPL	0.083	0.65	0.054	0.39	0.032	0.200	0.017
AC	0.083	0.36	0.030	0.44	0.037	0.500	0.042
AAE	0.083	0.29	0.024	0.24	0.020	0.090	0.007
Soc sus	0.333		**0.17**		**0.14**		**0.11**
ΣWi*Ii			**0.57**		**0.53**		**0.42**

(Analyzing from household survey, 2009-2010, legends see figure 5.1)

7.2.1.1. Sustainability assessment results of the rural vegetable cultivation systems

The aggregation of indicators with indicators is equal importance results in the table 6.5 shows that the aggregated value for ecological sustainability indicators is 0.18, and it revealed that ecological sustainability is 61.2% performs in its component of sustainability (0.33). For economic sustainability, the aggregate value is 0.23, and it means 72.6% achieves in economic sustainability. For social sustainability, aggregate value is 0.17, and accounts for 56.1% in the social sustainability. For overall sustainability, aggregate value is 0.57. The result indicates that the overall sustainability for this cropping system is conditional sustainable.

7.2.1.2. Sustainability assessment results of the peri-urban vegetable cultivation systems

The aggregate value for ecological sustainability is 0.13, and it accounts for 44.2% performs in its sustainability (0.33) that is low sustainability. For the economic sustainability, aggregate value is 0.26 means 85.8% performance in the sustainability. The social sustainability, the aggregate value is 0.14, and its performance is 46.2%in the sustainability. The overall sustainability index of the peri-urban vegetable cultivation systems is 0.53, and it can be concluded that the system is in conditional sustainable.

7.2.1.3. Sustainability assessment results of the urban vegetable cultivation systems

To assess the sustainability of each component of the system, the aggregate values for ecological, economical and social sustainability are 0.13, 0.18 and 0.11. The performances of each component are 47.6%, 59.4% and 36.3% in subtotal, respectively. So that we can conclude social sustainability is the weakest component among the basic of sustainable components. For overall assessment of the system, overall aggregate value is 0.42. The results indicate that the vegetable cultivation system in urban area is low sustainable condition.

7.2.2. Sustainability assessment by multicriteria evaluation method where indicators are unequal importance

The result from the weighting factors of all indicators in table 6.8, table 6.9 and table 6.10 in chapter 6, those score weights were used for aggregation using aggregation method in section 5.3.1.1 in chapter 5. The aggregation results are represented in the table 6.6.

The result of sustainability by muticriteria evaluation method shows that the highest value of sustainability index is the economic component with 0.54, 0.68 and 0.74 in urban, peri-urban and in the rural area, respectively. The lowest sustainability index is the social component in urban area (0.25). The sustainability assessment result with the highest value is the rural vegetable cultivation system (0.62), following is the peri-urban vegetable cultivation system (0.52), and the lowest sustainability index is the urban vegetable cultivation system with the value is 0.36 (Table 7.6).

Table 7.6. The results of sustainability by muticriteria evaluation method (Indicators are unequal importance)

Indicators	Rural area			Puri-urban area			Urban area		
	Wi	Ii	Wi*Ii		Wi	Ii	Wi*Ii		Wi
UCF	0.09	0.44	0.04	0.05	0.36	0.02	0.05	0.23	0.01
UOF	0.45	0.53	0.24	0.23	0.29	0.07	0.31	0.18	0.06
CLC	0.22	0.36	0.08	0.34	0.38	0.13	0.37	0.42	0.16
UCC	0.06	0.58	0.03	0.07	0.36	0.03	0.07	0.53	0.04
HH	0.17	0.72	0.12	0.31	0.59	0.18	0.2	0.61	0.12
Ecol sus	0.23	**0.51**	0.12	0.52	**0.42**	0.22	0.44	**0.38**	0.17
FR	0.25	0.72	0.18	0.3	1	0.30	0.39	0.8	0.31
IYT	0.16	0.64	0.10	0.54	0.59	0.32	0.44	0.33	0.15
EMC	0.59	0.68	0.40	0.16	0.77	0.12	0.17	0.48	0.08
Econ sus	0.65	**0.68**	0.44	0.33	**0.74**	0.24	0.17	**0.54**	0.09
ISS	0.12	0.78	0.09	0.12	0.6	0.07	0.12	0.55	0.07
EPL	0.26	0.65	0.17	0.4	0.39	0.16	0.47	0.2	0.09
AC	0.45	0.36	0.16	0.11	0.44	0.05	0.12	0.5	0.06
AAE	0.17	0.29	0.05	0.37	0.24	0.09	0.30	0.09	0.03
Soc sus	0.12	**0.47**	0.06	0.14	**0.37**	0.05	0.39	**0.25**	0.10
ΣWi*Ii			**0.62**			**0.52**			**0.36**

(Analyzing from household survey and stakeholder workshop, 2009-2010, legends see figure 5.1)

7.2.3. Sensitivity analysis

Sensitivity analyses are carried out by imposing some perturbation on the weights in order to determine the degree to which output of the weighting procedure will change. The results are represented in table 7.7.

Table 7.7. Sensitivity analysis for weights on (3) components of sustainability

Combination	Sustainability components	Wi	Rural area		Peri-urban area		Urban area	
			Ii	Wi*Ii	Ii	Wi*Ii	Ii	Wi*Ii
1	Econ sus	0.333	0.68	0.22	0.79	0.26	0.54	0.18
	Soc sus	0.333	0.52	0.17	0.42	0.14	0.34	0.11
	Ecol sus	0.333	0.53	0.18	0.40	0.13	0.39	0.13
ΣWi*Ii				**0.57**		**0.53**		**0.42**
Rank				**1**		**2**		**3**
2	Econ sus+0.033	0.366	0.68	0.25	0.79	0.29	0.54	0.20
	Soc sus-0.033	0.3	0.52	0.16	0.42	0.13	0.34	0.10
	Ecol sus	0.333	0.53	0.18	0.40	0.13	0.39	0.13
ΣWi*Ii				**0.58**		**0.55**		**0.43**
Rank				**1**		**2**		**3**
3	Econ sus-0.033	0.297	0.68	0.20	0.79	0.24	0.54	0.16
	Soc sus+0.033	0.363	0.52	0.19	0.42	0.15	0.34	0.12
	Ecol sus	0.34	0.53	0.18	0.40	0.13	0.39	0.13
ΣWi*Ii				**0.57**		**0.52**		**0.41**
Rank				**1**		**2**		**3**
4	Econ sus+0.033	0.363	0.68	0.25	0.79	0.29	0.54	0.20
	Soc sus	0.33	0.52	0.17	0.42	0.14	0.34	0.11
	Ecol sus-0.033	0.307	0.53	0.16	0.40	0.12	0.39	0.12
ΣWi*Ii				**0.58**		**0.55**		**0.43**
Rank				**1**		**2**		**3**
5	Econ sus-0.033	0.297	0.68	0.20	0.79	0.24	0.54	0.16
	Soc sus	0.33	0.52	0.17	0.42	0.14	0.34	0.11
	Ecol sus+0.033	0.373	0.53	0.19	0.40	0.14	0.39	0.14
ΣWi*Ii				**0.57**		**0.52**		**0.42**
Rank				**1**		**2**		**3**
6	Econ sus	0.33	0.68	0.23	0.79	0.26	0.54	0.18
	Soc sus-0.033	0.297	0.52	0.16	0.42	0.13	0.34	0.10
	Ecol sus+0.033	0.373	0.53	0.19	0.40	0.14	0.39	0.14
ΣWi*Ii				**0.57**		**0.53**		**0.42**
Rank				**1**		**2**		**3**
7	Econ sus	0.33	0.68	0.23	0.79	0.26	0.54	0.18
	Soc sus+0.033	0.363	0.52	0.19	0.42	0.15	0.34	0.12
	Ecol sus-0.033	0.307	0.53	0.16	0.40	0.12	0.39	0.12
ΣWi*Ii				**0.57**		**0.53**		**0.42**
Rank				**1**		**2**		**3**

(Analyzing from household survey, 2009-2010, legends see figure 5.1)

By imposing some perturbation on the weights, I attempted to determine the degree to which output of the weighting procedure will change. Accordingly, 10% change in three components of sustainability (± 0.033) perturbation on the weights is imposed, and this is carried through the aggregation procedure. The results are represented in the table 7.7. The overall sustainability has not much changed. The ranking of sustainability of each vegetable cultivation system has not changed. The results indicated that final rankings of sustainability for three vegetable cultivation systems in the study area are stable. The first ranking of sustainability is belonging to the rural area (MeLinh district), the second ranking is the peri-urban area (ThanhTri district), and the third ranking is the urban area (HaDong district), respectively. The results of the sensitive analysis, we can conclude that the errors in components weight can be considered insignificant.

7.3. Results of sustainability assessment by fuzzy evaluation method

The methodology for the sustainability assessment by fuzzy evaluation in section 5.3.2, chapter 5 was used for fuzzification and defuzzification of all indicators.

7.3.1. Fuzzification processes

7.3.1.1. Setting membership functions in the models

The membership functions for fuzification process were determined in chapter 5.

- For secondary variables: FR, IYT, EMC, ISS, EPL, AC, AAE, UCF, UOF, CLC, UCC, and HH are assigned with Trapezoidal-shaped built-in membership function “trapmf”. Membership functions and linguistic values are defined and represented in figure 7.1 and detained as follows:

  + MF1='low': 'trapmf', [-0.36 -0.04 0.2 0.4]
  + MF2='medium': 'trapmf', [0.25 0.4 0.6 0.75]
  + MF3='high': 'trapmf', [0.6 0.8 1.05 1.45]

Notes: trapmf = Trapezoidal-shaped built-in membership function,

MF = Membership function

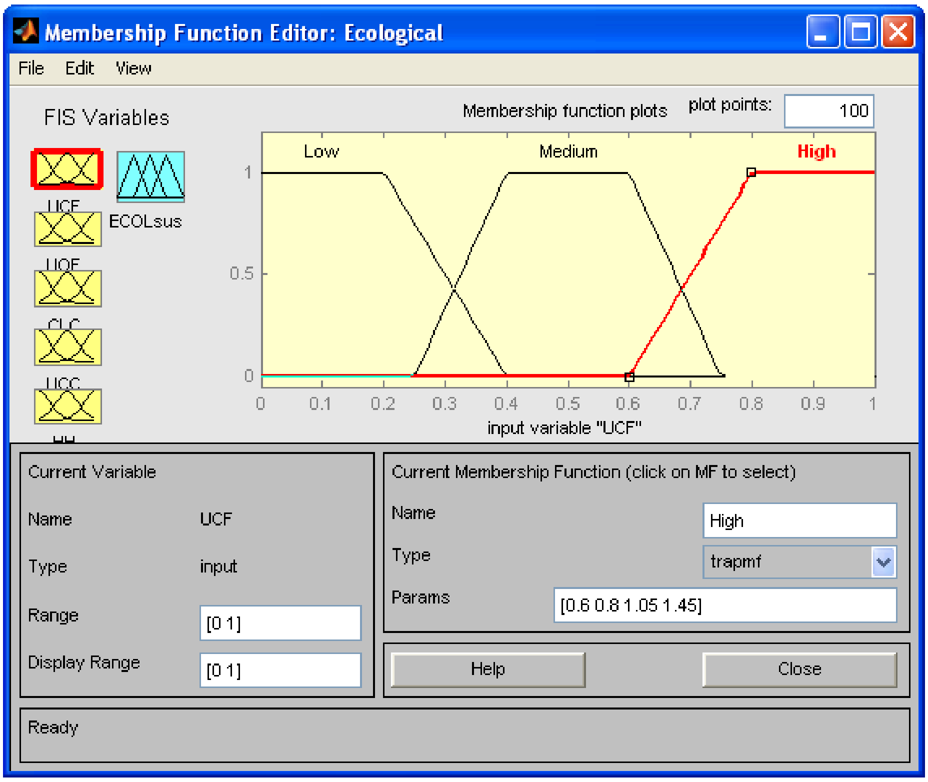

Figure 7.1. Setting membership functions for secondary variables using fuzzy logic toolbox in MATLAB 7.1

For example, to get the fuzzified value for UCF of vegetable cultivation systems in the rural area, normalized value for UCF is 0.44 and fall into membership function 2: MF2='medium': 'trapmf', [0.25 0.4 0.6 0.75] as a linguistic medium value.

- For primary variables: For primary variables: ECOLsus, ECONsus and SOCsus, and Osus are assigned with Gaussian curve built-in membership function “gaussmf”. Membership functions and linguistic values are defined and represented in figure 7.2 and detained as follows:

  + MF1='Vbad': 'gaussmf', [0.1062 0]
  + MF2='Bad': 'gaussmf', [0.1062 0.25]
  + MF3='Satisfactory': 'gaussmf', [0.1062 0.5]
  + MF4='Good': 'gaussmf', [0.1062 0.75]
  + MF5='Vgood': 'gaussmf', [0.1062 1]

Notes: gaussmf = Gaussian curve built-in membership function.

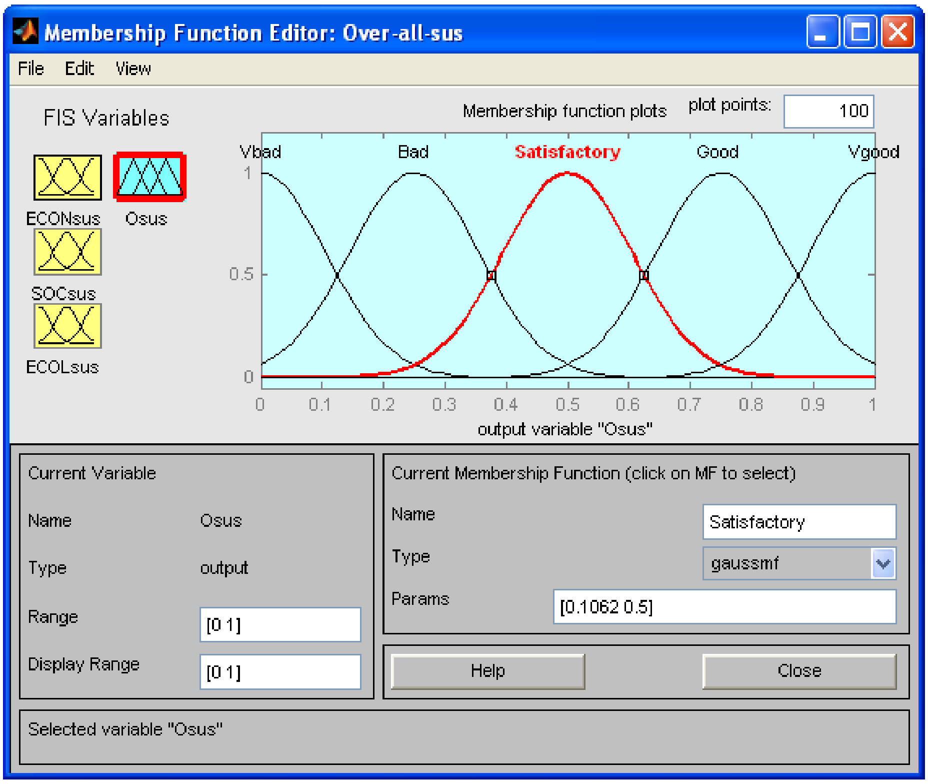

Figure 7.2. Setting the membership functions for primary variables using fuzzy logic toolbox in MATLAB 7.1

For example, the crisp value for ecological sustainability of vegetable cultivation systems in the rural area was 0.445 and its fall into membership function 3: MF3 = 'Satisfactory':'gaussmf', [0.1062 0.5] as a linguistic satisfactory value.

7.3.1.2. Adding linguistic rules and fuzzy operators

As mentioned in section 5.3.2.1 (the linguistic variables) in chapter 5 and Fuzzy rules determination result in chapter 6, total 476 rules are gathered (Appendix F). All rules are added as input of fuzzy inference system with its appropriate membership function. The results of this process are depicted in figure 7.3 and figure 7.4.

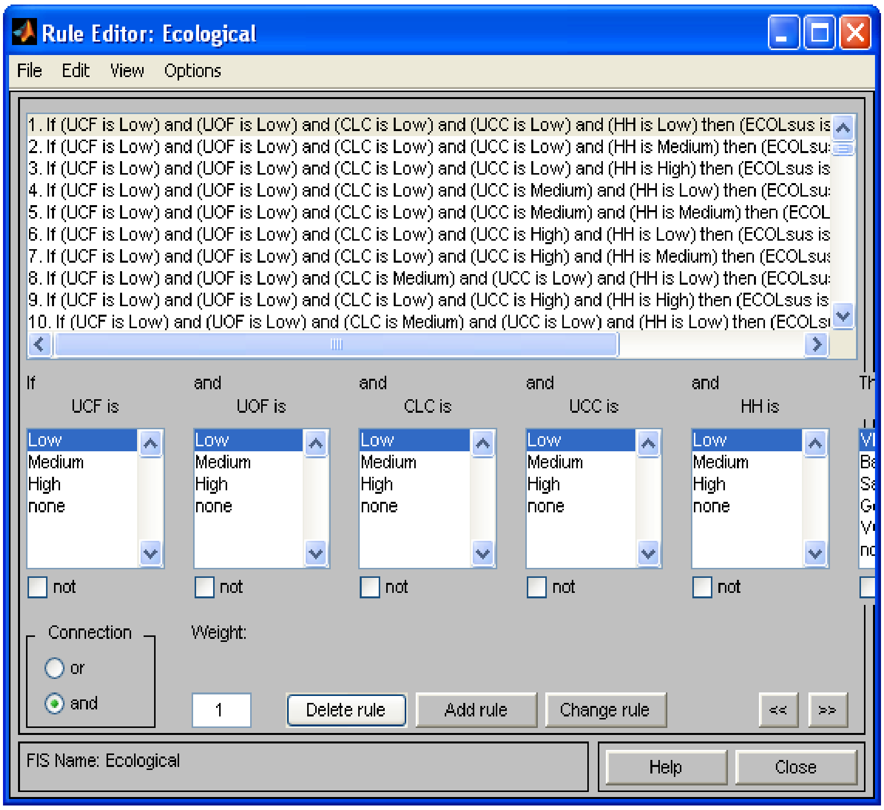

Figure 7.3. Implication of fuzzy rules editor in ecological sustainability assessment using fuzzy logic toolbox in MATLAB 7.1

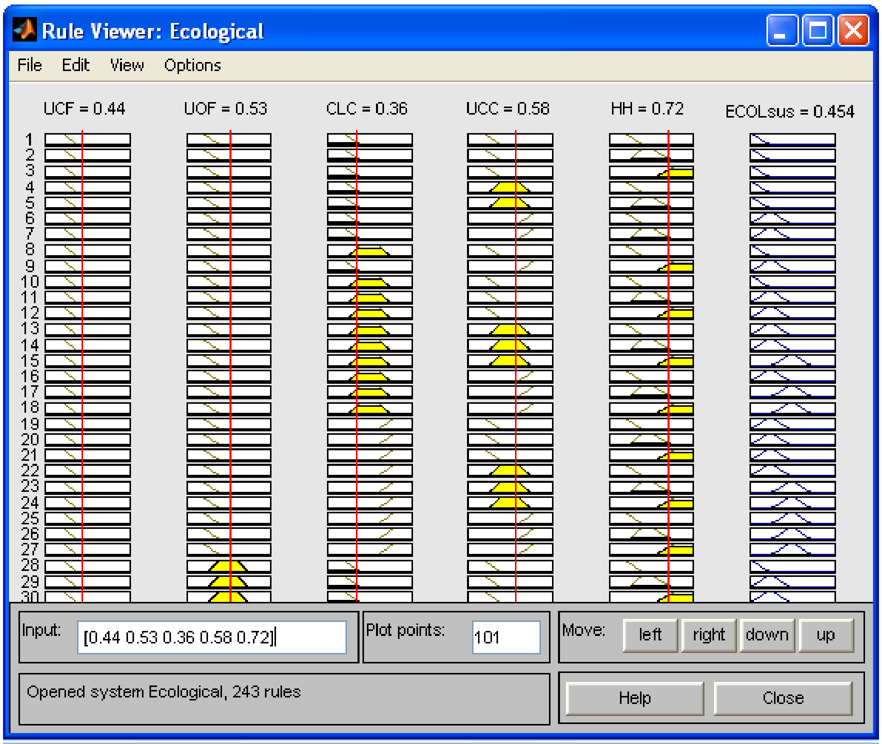

Figure 7.4. Implication of fuzzy rules viewer in ecological sustainability assessment using fuzzy logic toolbox in MATLAB 7.1

7.3.2. Defuzzication processes

Defuzzification process calculates the output crisp value from the aggregated resultant fuzzy set derived after rule evaluation. In this study, center of gravity method was used for defuzzification. Final crisp value for SOCsus can be observed in figure 7.5.

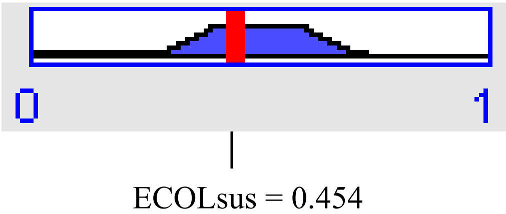

Figure 7.5. Graphical illustration of defuzzification of the fuzzy conclusion for social sustainability in the rural area (MeLinh district) using fuzzy logic toolbox in MATLAB 7.1

7.3.3. Results of sustainability assessment by fuzzy evaluation

To assess the overall sustainability of the vegetable cultivation systems, methodology from section 5.3.2 in chapter 5 was applied with the aid of fuzzy logic toolbox in MATLAB 7.1 software. The final value of overall sustainability was given in the form of a percentage from 0-100. The results of overall sustainability measurement and each component are summarized in table 7.8.

Table 7.8. Overall sustainability measurement for vegetable cultivation systems in the study area

Vegetable cultivation systems	Economical sustainability	Social sustainability	Ecological sustainability	Overall sustainability
Rural area (Melinh)	0.62 (Satisfactory)	0.45 (Satisfactory)	0.45 (Satisfactory)	0.57 (Satisfactory)
Peri-urbanarea (Thanhtri)	0.75 (Good)	0.32 (Bad)	0.42 (Satisfactory)	0.35 (Bad)
Urban area (Hadong)	0.5 (Satisfactory)	0.25 (Bad)	0.33 (Bad)	0.31 (Bad)

Notes: The assessment for 'Good', 'Satisfactory' and "Bad" were based on the set of function in session 5.3.2.3 (fuzzification) in chapter 5 (Analyzing from household survey and stakeholder workshop, 2009-2010).

7.3.3.1. Sustainability assessment results of the rural vegetable cultivation systems

The defuzzification process by sustainability assessment in fuzzy evaluation method for the rural vegetable cultivation systems shows the aggregate value for ecological sustainability and social sustainability are 0.45 and the highest aggregate value is belonging to the economical sustainability (0.62). So, we can identify as ‘satisfactory’ level of sustainability among five levels (very bad, bad, satisfactory, good, and very good). The aggregate value of overall sustainability is 0.57, so that can be identified as ‘satisfactory’ level of sustainability. We can conclude that the sustainability for this system is conditionally sustainable.

7.3.3.2. Sustainability assessment results of the peri-urban vegetable cultivation systems

According to the defuzzification results by sustainability assessment by fuzzy evaluation method for the vegetable cultivation system in the peri-urban area, the aggregate value for ecological sustainability is 0.32 and belonging to ‘bad’ level of sustainability. For economical sustainability, aggregate value is 0.75, so that can be identified as ‘good’ level of sustainability. In social sustainability, aggregate value is 0.42, so it can be identified as ‘satisfactory’ level of sustainability in aggregation. The aggregation result of the overall sustainability is0.35 and it can be assessed as ‘bad’ level of sustainability. The results indicated that the sustainability for this system is not sustainable.

7.3.3.3. Sustainability assessment results of the urban vegetable cultivation systems

The aggregation value result by the defuzzification process in sustainability assessment by fuzzy evaluation method shows that the social and ecological sustainability is 0.25 and 0.33 in the urban vegetable cultivation system. So, it falls to ‘bad’ level of sustainability. We can conclude that social and ecological sustainability for this system is not sustainable. For economical sustainability, aggregate value is 0.5, so that can be identified as ‘satisfactory’ level of sustainability. The overall sustainability of the urban vegetable cultivation system, the aggregation result is 0.31, and it can be assessed as ‘bad’ level of sustainability. This indicates that the urban vegetable cultivation system is not sustainable.

7.3.4. Sensitivity analysis

Sustainability assessment by fuzzy evaluation model is analyzed for all three components of sustainability using three different membership functions (section 5.5.2 in chapter 5). The outputs from the model are represented in table 7.9. The results show that the absolute quantitative performances for overall sustainability vary from 0.00 to 0.02 with the confidence level, but the degree of sustainability is not changed. So, we can conclude that the errors in input variables are insignificant for the final output.

Table 7.9. Output from the sensitivity analysis with the different confidence level for overall sustainability in three regions in the study area

Vegetable cultivation systems	Least confidence	Moderate confidence	Most confidence
Rural area (Melinh)	0.57 (Satisfactory)	0.57 (Satisfactory)	0.57 (Satisfactory)
Peri-urbanarea (Thanhtri)	0.33 (Bad)	0.35 (Bad)	0.33 (Bad)
Urban area (Hadong)	0.31 (Bad)	0.31 (Bad)	0.31 (Bad)

Notes: The assessment for ‘Satisfactory’ and “Bad” were based on the set of function in 5.3.2.3 (fuzzification) in chapter 5 (Analyzing from household survey, 2009-2010).

7.4. Representation and assessment of the solution

An important feature of the AMOEBA approach is the representation and the assessment of each solution, once sustainability indicators have been calculated. The representation must be integration, involving all the objectives taken into account.

The advantage of AMOEBA diagram is first clear and global representation of all the indicators and their associated value. Secondly, solutions can be easily compared. The results of associated value of the indicators and representation by AMOEBA diagram for three vegetable cultivation systems are illustrated in figure 7.6.

The sustainability of three vegetable cultivation systems is easily compared in each indicator and overall by visualization; the best one is furthest to the center. By reading the diagram, most of the indicators in the rural vegetable cultivation system are the furthest to the center to compare with other regions, and we can conclude that it has the highest sustainability.

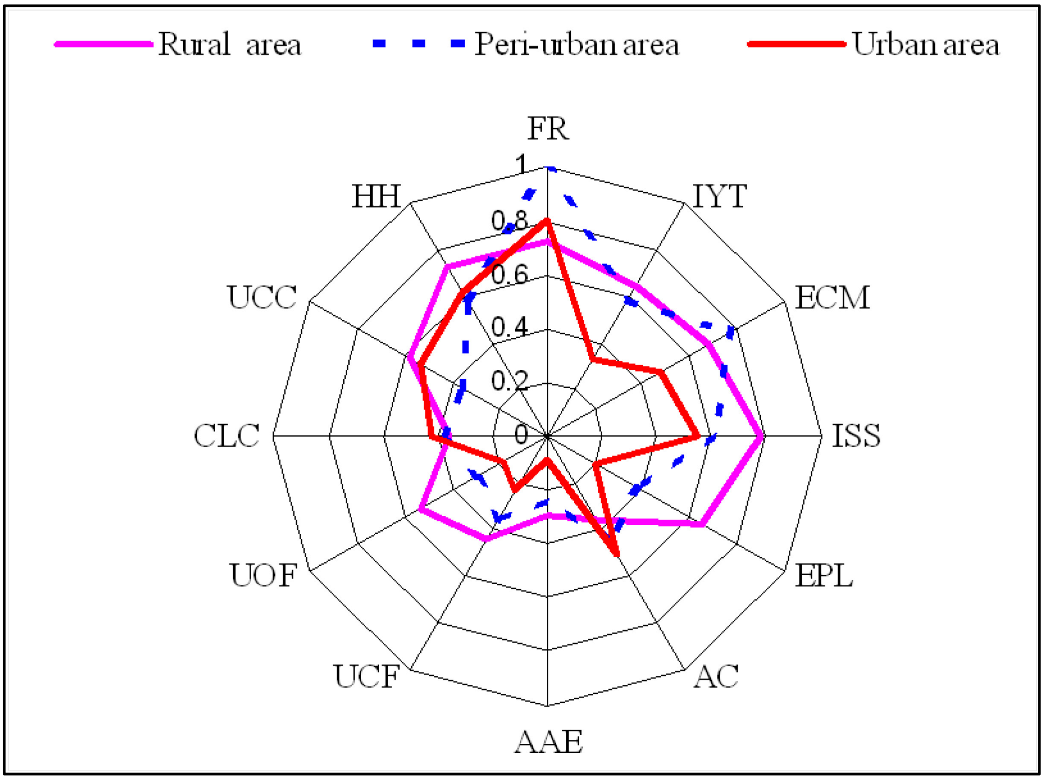

Figure 7.6. Representation of sustainability assessment by Amoeba diagram for vegetable cultivation systems in the study area (legends see figure 5.1)

When we observed the diagram, we can easily distinguish that the sustainable indicator such as UCF, UCC in the peri-urban and urban vegetable cultivation systems are low. Farmers in the rural and peri-urban vegetable cultivation systems have limitation to access to agricultural extension. The trend of labor involved to vegetable production in urban area decreased, and its sustainable value is low. In this approach, solutions can be easily compared and weak area to improve will be straight visible.

7.5. Discussion

The results from the sustainability assessment for the vegetable cultivation systems show that in the rural area, the sustainability are acceptable whereas in the peri-urban area are only conditionally acceptable, and in the urban area are not sustainable.

Multi-criteria methods of evaluation are gaining attention among the economic community (BANA 1990, NIJKAMP *et al.* 1990, VAN DEN BERGH and NIJKAMP 1991, MUNDA *et al.* 1994). Multi-criteria evaluation has demonstrated its usefulness in conflict management for many environmental management problems (MUNDA *et al.* 1994). The major strength of multi-criteria methods is their ability to address problems marked by various conflicting evaluations.

Fuzzy uncertainty, in contrast, relates to events that have no well-defined, unambiguous meaning (KOSKO 1992). Fuzzy set theory is based on multi-valued logic (MC NEILL and FREIBERGER 1993, PEDRYCZ 1993, KLIR and YUAN 1998, ZIMMERMANN 1996). Multi-valued logic enables intermediate assessment between strictly sustainable and strictly unsustainable; i.e., fuzziness describes the degree to which an event occurs, not whether it occurs (KOSKO 1990, KOSKO 1992).

Sustainability assessment by fuzzy evaluation method appears to be well suited to provide quantitative answers pertaining to sustainability. Fuzzy model admits new parameters according to need and eliminates old ones if they have no effects on the results. Also one can build different fuzzy rules and the choice of sustainability indicators depends on the interest of operator as well as condition of the system. Defining appropriate indicators, collecting the relevant data, and choosing adequate fuzzy operators are indispensable steps to achieve a better assessment.

Fuzzy logic operations compensate for the lack of full knowledge of our system. Uncertainty is ubiquitous in sustainability problems since we never have complete knowledge of the ecological systems or the human society. We are not even capable as well of predicting all the effects of human actions on ecological systems and vice-versa. The sustainability assessment by fuzzy evaluation model provides a practical tool to manage and to predict, to some extent, the global evolution of the overall system.

The sustainability assessment by fuzzy evaluation approach proposed in this research exhibits three important characteristics. First, it permits the combination of various aspects of sustainability with different units of measurement. Second, it overcomes the difficulty of assessing certain attributes or indicators of sustainability without precise quantitative criteria. Third, the methodology is easy to use and interpret. Values of sustainability can be derived, and comparisons made over different areas or times. Therefore, this model has the potential to become a practical tool to policymakers and scientists.

The results indicate that to achieve the vegetable productions in terms of both the qualitative, quantitative, and environmental sustainability that would meet human's living standard demand and sustainable development in the future is essential for vegetable cultivation systems in Red River Delta, Vietnam. Therefore, farmers and decision maker have to solve some disadvantages and constraints, especially in food quality and environment; change of the conventional cultivation habit. It is necessary to emphasize supervision and management because producers regard yield as the most important objective regardless of quality and environmental sustainability. Arrangements to supplement limited manure to supply in the peri-urban and urban areas should be made. The involvement of the private sector in the input supply system and the output market needs to be strengthened. To gradually accomplish establishment of national standards, it is a necessary action as soon as possible. A completed standard system will facilitate better examinations, supervision of enterprises and individuals if they properly abide regulations, policies on environmental protection in local and international markets. Support vegetable producer in capital, technologies and information.

To achieve sustainable vegetable production in the Red River Delta, Vietnam, the farmers need to be trained, need improved internal controls and tracing systems as well as strict social control in order to implement good agricultural practice guidelines for production of vegetables such as VIETGAP (VIETGAP was established base on ASEANGAP, EUROPGAP, GLOBALGAP and FRESHCARES)in order to enhance the harmonization of product standards and facilitate the trade of fruit and vegetables in ASEAN and the world, towards the establishment of sustainable vegetable production in the future.

8. CONCLUSIONS

In the last decade food safety crises, revelations of unethical working conditions for farmers, increasing attention to symptoms of imbalance such as pollution and decline of biodiversity have dramatically demonstrated the needs for a sustainable approach to agriculture. In developing countries the right attention and attitude to address the future challenge in agricultural production will be essential to contribute to sustainable development. For the reason of the importance of sustainable agriculture for all the human beings, this study aims to contribute the knowledge about sustainability in the vegetable sector of the country. The sustainability assessment framework in this study was distilled the relevant principles from the literature on agro-ecology and sustainable agriculture and turning these into requirements. The sustainability indicators in this study were decided which criteria best fit with the context of Vietnam and covers three dimensions of agricultural sustainability and theoretically well founded, relatively stable and independent, clear in content, measurable and comparable, easy to quantify, regionally specific adapted, and based on acquirable data. The framework and the criteria are basic line for answering the research questions of this study.

8.1. The characteristics of the vegetable cultivation systems in the Red River Delta in Vietnam

The results of this study depicted the overall picture of the vegetable cultivation systems in the Red River Delta, Vietnam. The study results indicated that, apart from the advantages in natural conditions and abundant labor force, the vegetable sector in Vietnam had lots of disadvantages and constraints such as:

- The vegetable cultivation systems differ in three study area. Farm size and plot size are small (double large in the rural to compare with the urban area). In the rural area, the farm size is not enough to intensive vegetable cultivation.
- Family labor involved to vegetable production in the rural area higher three times than in the urban area.
- In the peri-urban area, there are four cropping patterns but in the rural and urban only three.
- Organic fertilizer used in the rural higher than in the urban and in the peri-urban area.

- Seeds are mainly purchased from village shops. Most of the seed sources do not provide authenticated and pure seed. Only a small percentage of farmers bought seed from input/output dealers who probably supply better quality seed.
- The indiscriminate use of pesticide on crops, especially on vegetables, has serious health and environmental consequences and vegetable cultivation in the urban and peri-urban is threatened with serious contamination problems.
- Poor post harvest practices that led to bruise and skin blemishes and short shelf life of vegetables.
- There are none of the dedicated cold storage facilities offering. There are very poor links between producers and consumers.
- There are none of the long-term contracts between the growers and collectors - exporters - processors, and less commitment from the growers in implementing product supply agreements. The output market for vegetables is unstable.
- The number of farm-household fed cattle and buffalo in the rural area have been decreasing, and none of the farm-households in the urban area kept cattle and buffalo that consequence to the limited availability of animal manure in peri-urban and urban areas.
- The vegetable grower in urban areas has limited access to agricultural extension than vegetable growers in peri-urban and in rural areas.
- No documents and records of the vegetable growers such as production, fertilizers usage, pesticides usage, and post harvest.
- The transportation and irrigation systems have not been appropriated investment.
- Urban and peri-urban agriculture in the study area have been threatened by urbanization and industrialization.

8.2. Sustainability level of different vegetable cultivation systems in the study area

According to sustainability index for each indicator of the vegetable cultivation systems the study area we can observe the weakest indicators among the systems is access to agricultural extension in the urban area. The second low index for sustainability of the system is found in use of organic fertilizers. In Vietnam, to partial fulfill the requirement of fertilizers for nutrient cycling in the cropping systems, the production and utilization of bio-fertilizers were being encouraged and campaigned. But still farmers' perception to use bio-fertilizers was low and not enough organic manure and plant residues for nutrient cycling that farmers' usage.

The third weakness indicator is usage of chemical control in the vegetable systems. The usage of pesticides or chemical control is non-sustained condition. In Vietnam, pertaining to plant protection, integrated pest management has been introduced for major crops. Systematic use of pesticides was demonstrated to the farmers by using scouting techniques, setting economic threshold levels and making decision for appropriate spraying. The results of this study indicate that even though attempts for integrated pest management are continuing, farmer's knowledge in this practice is still not fully accepted.

In Vietnam, the level of chemicals fertilizer use in agriculture is considerable high. Farmers' usage of chemical fertilizer is unsustainable condition, but it can be seen that in the future land productivity (yield) could not meet the optimum.

Three study areas have been considerably different in sustainability: The urban vegetable cultivation system is not sustainable. The peri-urban and rural vegetable cultivation systems are conditional sustainable. They differ in overall sustainability and in the three dimensions (ecological, economic and social).

The sustainability assessment results by multicriteria evaluation method (with indicators are equal importance) gave the highest value for the rural vegetable cultivation system (0.57), following is the peri-urban vegetable cultivation system (0.53), and the lowest sustainability index is the urban vegetable cultivation system with the value is 0.43.

The result of sustainability by muticriteria evaluation method (with indicators are unequal importance) showed the value of sustainability index with 0.62, 0.52 and 0.36 in the rural, peri-urban and urban vegetable cultivation systems, respectively.

According to five linguistic rules: very bad, bad, satisfactory, good and very good, the rural vegetable cultivation system has the satisfactory level of sustainability (0.57), the peri-urban and urban vegetable cultivation systems have 'bad' level of sustainability (0.35) and (0.31), respectively.

In summary, the vegetable cultivation system in the rural and the peri-urban area are conditional sustainable or satisfactory but the sustainability of some indicators is low. The urban vegetable cultivation systems are not sustainable or bad sustainable condition.

8.3. Differences among sustainability assessment methods

Three sustainability assessment methods give similar results. Among three assessment methods (Table 8.1), sustainability assessment by fuzzy evaluation approach appears to be well suited to provide quantitative answers pertaining to sustainability. The fuzzy evaluation method gives the lowest sustainability index among the methods but this is the best method reflects the real situation. Fuzzy logic operations compensate for the lack of full knowledge of our system. Uncertainty is ubiquitous in sustainability problems since we never have complete knowledge of the ecological systems or the human society. We are not even capable as well of predicting all the effects of human actions on ecological systems and vice-versa. The sustainability assessment by fuzzy evaluation model provides a practical tool to manage and to predict, to some extent, the global evolution of the overall system. The methods using unequal indicators (AHP and FIS) involving to the farmers and considered to their knowledge. Therefore, those methods give more reliable results.

Table 8.1. Comparison among the sustainability assessment methods

Attributes	Fuzzy evaluation	Multi-criteria evaluation	
		AHP	Indicators are equal importance
Handling uncertainty in the problems	By fuzzification	By probability	By scoring
Overall assessments	Permits the combination of various aspects of sustainability	Apply weights and integration	computation
Assessing attributes	By normalization (overcome the problem of more is better or less is better)	By normalization (overcome the problem of more is better or less is better)	By scoring
Interpretation	Assess by intermediate levels between yes and no	Comparing	Comparing
Decision making	Comparing	Allow compromise solution	Comparing
Handling	Need fuzzy logic and to apply analytical skill	Need to apply reasonable weights	Simple calculation

The second suitable method for sustainability assessment is the multi-criteria evaluation with indicators is unequal importance. The major strength of multi-criteria methods is their ability to address problems marked by various conflicting evaluations.

Third suitable method for sustainability assessment method is the multi-criteria evaluation with indicators is equal importance. It simply aggregates and integrates diverse information into a meaningful form. In this method, less data and analytical skills are required.

9. RECOMMENDATIONS

9.1. Recommendations

From finding of this study, we derive recommendations to enhance the efficiency of the ongoing and future for the vegetable cultivation systems in the Red River Delta, Vietnam. The urgent calling to the researcher, all the institutions and government should have specific action to orientate farmers in order to archive both the qualitative, quantitative, and environmental sustainability that would meet the GAP standard demand for sustainable vegetable development in the future in Red River Delta, Vietnam. The specific recommendation as following:

- Vegetable cultivation systems in the study area are small-scale and fragmented so that the needs in the future are undertaking land consolidation.
- Balanced and integrated use of mineral fertilizers together with organic fertilizers bases on soil tests, promise long-term productivity with sufficient economic returns are needed to manage.
- Improving the quality of seeds and seed supply systems.
- To encourage including legume crops in the cropping systems to supplement N requirement and increase the organic material content in soil.
- To enhance the efficiency of fertilizers applied by controlling nutrient leaching through appropriate methods of irrigation and fertilizer application.
- In order to reduce farmers' dependency on harmful chemical control measures, it is necessary to promote non-conventional measures of insects and pest control, including herbal insecticides and promotion of insect and pest predators.
- Vegetable production in the study area is financially viable, but economically not viable. The profitability of crops is affected by changes of input costs and output prices. So, reliable and efficient market system is recommended.
- The current extension services are not adequate to encourage the farmers to adopt resource-conservation services. So, agricultural extension workers should receive adequate motivation to provide efficient services to farmers. One of the primary responsibilities of the extension service should be to make farmers aware of the long-term environmental and economic implications of the inappropriate use of resources, including external inputs and usage of irrigation water.

- Contract farming has the potential to provide farmers with improved technology, and a stable markets need to be promoted.
- New technology, information and news concern about sustainable agriculture should be transmitted by TV program, radio, newspaper and journals to the farmers.
- Government programs aimed at up-grading equipment and machinery used in fruit and vegetable processing.
- Coordination among different research institutes, centers, and stations should be strengthened.
- Responsibilities should be delegated among institutions involved in research and to properly invest in scientific research.
- The government should facilitate private and public investments in storage (including cold storage) for the fruit and vegetable sectors.
- The justification for public investment in infrastructure, such as roads, irrigation systems, urban planning, environmental planning.
- Development of domestic market specifically aimed at improving agricultural marketing, such as the construction of market places, and export market.
- Strengthening the role of fruits and associations to promote the relationship between members and the association and international assistance and cooperation programs should be promoted.
- There should be appropriate policies to support the promotion of exports, loans, taxes, freight costs and certified quality management processes... for investment, consumption of vegetable production results.
- Stronger political commitment to the vegetable research and development program through specific policies, priorities, and measures should be established.
- The government should devote more attention and resources to sanitary and phyto-sanitary issues in fruit and vegetable production.
- Support farmers and enterprises with training courses for production of vegetables according to GAP.

9.2. Limitations and suggestion for further study

- An important part of this study aims to assess the sustainability of vegetable cultivation systems in three dimensions of sustainability in agriculture. The financial return, index of yield trend, efficiency of market channel, use of chemical fertilizer, use of organic fertilizer, cultivation of legume crop, use of chemical control, human health, input self sufficiency, employment, access to credit and access to agricultural extension are used as indicators. However, there is other indicators, for example, food security, gender equity, agricultural diversity, etc that are also important but was not taking in to account in this study.

- In this study, the multicriteria evaluation and fuzzy evaluation methods were used for sustainability assessment. Even though there methods have its advantages but are not the optimal method. So other method should be used.
- Building the soil databases is needed, and the land suitability assessment should be carried out to determine, which is the suitable crop should be grown in order to support farmer and decision makers in their decision for sustainable agriculture.
- The water-quality issue in the peri-urban and urban area in Vietnam needs investigation to determine the problem and attend to the sources of pollution. Studies are also needed to verify whether the use of groundwater for irrigation that leads to depletion of the aquifers.

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APPENDICES

Appendices a-1: AHP calculation for Me Linh district

1. Economic indicators

Consistent matrix

	FR	YIT	EMC
FR	1	2	0.33
YIT	0.5	1	0.33
EMC	3	3	1
Sum	4.5	6	1.67

Calculate priorities

	FR	YIT	EMC	**W**
FR	0.22	0.33	0.20	**0.25**
YIT	0.11	0.17	0.20	**0.16**
EMC	0.67	0.50	0.60	**0.59**

Size of matrix is 3; random consistency RI is equal 0.58 and CR < 0.10

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.0270

CR = CI/RI = 0.0465

2. Social indicators

Consistent matrix

	ISS	EPL	AC	AAE
ISS	1	0.5	0.33	0.5
EPL	2	1	0.5	2
AC	3	2	1	3.00
AAE	2	0.5	0.33	1
Sum	8	4	2.17	6.5

Calculate priorities

	ISS	EPL	AC	AAE	**W**
ISS	0.13	0.13	0.15	0.08	**0.12**
EPL	0.25	0.25	0.23	0.31	**0.26**
AC	0.38	0.50	0.46	0.46	**0.45**
AAE	0.25	0.13	0.15	0.15	**0.17**

Size of matrix is 4, random consistency RI is equal 0.9 and CR < 0.10

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.0239

CR = CI/RI = 0.0265

Appendices a-1: AHP calculation for Me Linh district

2. Environmental indicators

Consistent matrix

	UCF	UOF	CLC	UCC	HH
UCF	1	0.2	0.33	2	0.33
UOF	5	1	3	5	3
CLC	3	0.33	1	3	2
UCC	0.5	0.2	0.33	1	0.33
HH	3.0	0.33	0.5	3	1
Sum	12.5	2.07	5.17	14	6.67

Calculate priorities

	UCF	UOF	CLC	UCC	HH	**W**
UCF	0.08	0.10	0.06	0.14	0.05	**0.09**
UOF	0.40	0.48	0.58	0.36	0.45	**0.45**
CLC	0.24	0.16	0.19	0.21	0.30	**0.22**
UCC	0.04	0.10	0.06	0.07	0.05	**0.06**
HH	0.24	0.16	0.10	0.21	0.15	**0.17**

Size of matrix is 5 so that Random consistency RI is equal 1.12 and CR < 0.10

CI = $((\lambda_{max}-n)/n-1) = 0.0449$

CR = CI/RI = 0.0401

3. Overall sustainability indicators

Consistent matrix

	ECONsus	SOCsus	ECOLsus
ECONsus	1	5	3
SOCsus	0.20	1	0.5
ECOLsus	0.33	2	1
Sum	1.53	8	4.5

Calculate priorities using approximation method

	ECONsus	SOCsus	ECOLsus	**W**
ECONsus	0.65	0.63	0.67	**0.65**
SOCsus	0.13	0.13	0.11	**0.12**
ECOLsus	0.22	0.25	0.22	**0.23**

Size of matrix is 3, so that Random consistency RI is equal 0.58 and CR < 0.10

CI = $((\lambda_{max}-n)/n-1) = 0.0018$

CR = CI/RI = 0.0032

Appendices a-2: AHP calculation for Thanh Tri district

1. Economic indicators

Consistent matrix

	FR	YIT	EMC
FR	1	0.5	2
YIT	2	1	3
EMC	0.5	0.33	1
Sum	3.5	1.83	6

Calculate priorities

	FR	YIT	EMC	**W**
FR	0.29	0.27	0.33	**0.30**
YIT	0.57	0.55	0.50	**0.54**
EMC	0.14	0.18	0.17	**0.16**

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.00460

CR = CI/RI = 0.00794

2. Social indicators

Consistent matrix

	ISS	EPL	AC	AAE
ISS	1	0.33	1	0.33
EPL	3	1	4	1
AC	1	0.25	1	0.33
AAE	3	1	3	1
Sum	8	2.58	9	2.67

Calculate priorities

	ISS	EPL	AC	AAE	**W**
ISS	0.13	0.13	0.11	0.13	**0.12**
EPL	0.38	0.39	0.44	0.38	**0.40**
AC	0.13	0.10	0.11	0.13	**0.11**
AAE	0.38	0.39	0.33	0.38	**0.37**

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.00346

CR = CI/RI = 0.00384

Appendices a-2: AHP calculation for Thanh Tri district

3. Environmental indicators

Consistent matrix

	UCF	UOF	CLC	UCC	HH
UCF	1	0.33	0.2	0.5	0.17
UOF	3	1	1	5	0.5
CLC	5	1	1	5	2
UCC	2.0	0.2	0.2	1	0.2
HH	6.0	2	0.5	5	1
Sum	17	4.53	2.9	16.5	3.87

Calculate priorities

	UCF	UOF	CLC	UCC	HH	**W**
UCF	0.06	0.07	0.07	0.03	0.04	**0.05**
UOF	0.18	0.22	0.34	0.30	0.13	**0.23**
CLC	0.29	0.22	0.34	0.30	0.52	**0.34**
UCC	0.12	0.04	0.07	0.06	0.05	**0.07**
HH	0.35	0.44	0.17	0.30	0.26	**0.31**

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.0598

CR = CI/RI = 0.0534

4. Overall sustainability indicators

Consistent matrix

	ECONsus	SOCsus	ECOLsus
ECONsus	1	3	0.5
SOCsus	0.33	1	0.33
ECOLsus	2	3	1
Sum	3.33	7	1.83

Calculate priorities using approximation method

	ECONsus	SOCsus	ECOLsus	**W**
ECONsus	0.30	0.43	0.27	**0.33**
SOCsus	0.10	0.14	0.18	**0.14**
ECOLsus	0.60	0.43	0.55	**0.52**

CI = $((\lambda_{max}\text{-}n)/n\text{-}1)$ = 0.0269

CR = CI/RI = 0.0464

Appendices a-3: AHP calculation for Ha Dong district

1. Economic indicators

Consistent matrix

	FR	YIT	EMC
FR	1	1	2
YIT	1	1	3
EMC	0.5	0.33	1
Sum	2.5	2.33	6

Calculate priorities using approximation method

	FR	YIT	EMC	**W**
FR	0.4	0.43	0.33	**0.39**
YIT	0.4	0.43	0.50	**0.44**
EMC	0.2	0.14	0.17	**0.17**

CI = $((\lambda_{max}\text{-n})/\text{n-1})$ = 0.009

CR = CI/RI = 0.016

2. Social indicators

Consistent matrix

	ISS	EPL	AC	AAE
ISS	1	0.2	1	0.5
EPL	5	1	5	1
AC	1	0.2	1	0.50
AAE	2	1	2	1
Sum	9	2.4	9	3

Calculate priorities

	ISS	EPL	AC	AAE	**W**
ISS	0.11	0.08	0.11	0.17	**0.12**
EPL	0.56	0.42	0.56	0.33	**0.47**
AC	0.11	0.08	0.11	0.17	**0.12**
AAE	0.22	0.42	0.22	0.33	**0.30**

CI = $((\lambda_{max}\text{-n})/\text{n-1})$ = 0.035

CR = CI/RI = 0.039

Appendices a-3: AHP calculation for Ha Dong district

3. Environmental indicators

Consistent matrix

	UCF	UOF	CLC	UCC	HH
UCF	1	0.2	0.2	0.5	0.17
UOF	5	1	1	5	2
CLC	5	1	1	5	4
UCC	2.0	0.2	0.2	1	0.2
HH	6.0	0.5	0.25	5	1
Sum	19	2.9	2.65	16.5	7.37

Calculate priorities using approximation method

	UCF	UOF	CLC	UCC	HH	**W**
UCF	0.05	0.07	0.08	0.03	0.02	**0.05**
UOF	0.26	0.34	0.38	0.30	0.27	**0.31**
CLC	0.26	0.34	0.38	0.30	0.54	**0.37**
UCC	0.11	0.07	0.08	0.06	0.03	**0.07**
HH	0.32	0.17	0.09	0.30	0.14	**0.20**

CI = ((λ_{max}-n)/n-1) = 0.076

CR = CI/RI = 0.068

4. Overallsustainability indicators

Consistent matrix

	ECONsus	SOCsus	ECOLsus
ECONsus	1	0.5	0.33
SOCsus	2	1	1
ECOLsus	3	1	1
Sum	6	2.5	2.33

Calculate priorities

	ECONsus	SOCsus	ECOLsus	**W**
ECONsus	0.17	0.20	0.14	**0.17**
SOCsus	0.33	0.40	0.43	**0.39**
ECOLsus	0.50	0.40	0.43	**0.44**

CI = ((λ_{max}-n)/n-1) = 0.009

CR = CI/RI = 0.016

Appendices b-1: Rule application for overall sustainability assessment

Ordinal	IF (ECONsus)	AND (SOCsus)	AND (ECOLsus)	THEN (Osus)
1	Vbad	Vbad	Vbad	Vbad
2	Vbad	Bad	Vbad	Vbad
3	Vbad	Satisfactory	Vbad	Bad
4	Vbad	Good	Vbad	Bad
5	Vbad	Vgood	Vbad	Bad
6	Bad	Vbad	Vbad	Vbad
7	Bad	Bad	Vbad	Bad
8	Bad	Satisfactory	Vbad	Bad
9	Bad	Good	Vbad	Bad
10	Bad	Vgood	Vbad	Bad
11	Satisfactory	Vbad	Vbad	Bad
12	Satisfactory	Bad	Vbad	Bad
13	Satisfactory	Satisfactory	Vbad	Bad
14	Satisfactory	Good	Vbad	Bad
15	Satisfactory	Vgood	Vbad	Bad
16	Good	Vbad	Vbad	Bad
17	Good	Bad	Vbad	Bad
18	Good	Satisfactory	Vbad	Bad
19	Good	Good	Vbad	Bad
20	Good	Vgood	Vbad	Bad
21	Vgood	Vbad	Vbad	Bad
22	Vgood	Bad	Vbad	Bad
23	Vgood	Satisfactory	Vbad	Bad
24	Vgood	Good	Vbad	Bad
25	Vgood	Vgood	Vbad	Bad
26	Vbad	Vbad	Bad	VBad
27	Vbad	Bad	Bad	Bad
28	Vbad	Satisfactory	Bad	Bad
29	Vbad	Good	Bad	Bad
30	Vbad	Vgood	Bad	Bad
31	Bad	Vbad	Bad	Bad
32	Bad	Bad	Bad	Bad
33	Bad	Satisfactory	Bad	Bad
34	Bad	Good	Bad	Bad
35	Bad	Vgood	Bad	Bad

Appendices b-1: Rule application for overall sustainability assessment (cont.)

Ordinal	IF (ECONsus)	AND (SOCsus)	AND (ECOLsus)	THEN (Osus)
36	Satisfactory	Vbad	Bad	Bad
37	Satisfactory	Bad	Bad	Bad
38	Satisfactory	Satisfactory	Bad	Bad
39	Satisfactory	Good	Bad	Satisfactory
40	Satisfactory	Vgood	Bad	Satisfactory
41	Good	Vbad	Bad	Bad
42	Good	Bad	Bad	Bad
43	Good	Satisfactory	Bad	Satisfactory
44	Good	Good	Bad	Satisfactory
45	Good	Vgood	Bad	Satisfactory
46	Vgood	Vbad	Bad	Bad
47	Vgood	Bad	Bad	Bad
48	Vgood	Satisfactory	Bad	Bad
49	Vgood	Good	Bad	Bad
50	Vgood	Vgood	Bad	Satisfactory
51	Vbad	Vbad	Satisfactory	VBad
52	Vbad	Bad	Satisfactory	Bad
53	Vbad	Satisfactory	Satisfactory	Bad
54	Vbad	Good	Satisfactory	Bad
55	Vbad	Vgood	Satisfactory	Bad
56	Bad	Vbad	Satisfactory	Bad
57	Bad	Bad	Satisfactory	Bad
58	Bad	Satisfactory	Satisfactory	Bad
59	Bad	Good	Satisfactory	Bad
60	Bad	Vgood	Satisfactory	Satisfactory
61	Satisfactory	Vbad	Satisfactory	Bad
62	Satisfactory	Bad	Satisfactory	Bad
63	Satisfactory	Satisfactory	Satisfactory	Good
64	Satisfactory	Good	Satisfactory	Satisfactory
65	Satisfactory	Vgood	Satisfactory	Good
66	Good	Vbad	Satisfactory	Bad
67	Good	Bad	Satisfactory	Bad
68	Good	Satisfactory	Satisfactory	Satisfactory
69	Good	Good	Satisfactory	Good
70	Good	Vgood	Satisfactory	Good

Appendices b-1: Rule application for overall sustainability assessment (cont.)

Ordinal	IF (ECONsus)	AND (SOCsus)	AND (ECOLsus)	THEN (Osus)
71	Vgood	Vbad	Satisfactory	Bad
72	Vgood	Bad	Satisfactory	Bad
73	Vgood	Satisfactory	Satisfactory	Good
74	Vgood	Good	Satisfactory	Good
75	Vgood	Vgood	Satisfactory	Good
76	Vbad	Vbad	Good	Vbad
77	Vbad	Bad	Good	Bad
78	Vbad	Satisfactory	Good	Bad
79	Vbad	Good	Good	Bad
80	Vbad	Vgood	Good	Bad
81	Bad	Vbad	Good	Bad
82	Bad	Bad	Good	Bad
83	Bad	Satisfactory	Good	Satisfactory
84	Bad	Good	Good	Satisfactory
85	Bad	Vgood	Good	Satisfactory
86	Satisfactory	Vbad	Good	Bad
87	Satisfactory	Bad	Good	Satisfactory
88	Satisfactory	Satisfactory	Good	Satisfactory
89	Satisfactory	Good	Good	Good
90	Satisfactory	Vgood	Good	Good
91	Good	Vbad	Good	Bad
92	Good	Bad	Good	Satisfactory
93	Good	Satisfactory	Good	Good
94	Good	Good	Good	Good
95	Good	Vgood	Good	Good
96	Vgood	Vbad	Good	Bad
97	Vgood	Bad	Good	Satisfactory
98	Vgood	Satisfactory	Good	Good
99	Vgood	Good	Good	Good
100	Vgood	Vgood	Good	Vgood
101	Vbad	Vbad	Vgood	Vbad
102	Vbad	Bad	Vgood	Bad
103	Vbad	Satisfactory	Vgood	Bad
104	Vbad	Good	Vgood	Bad
105	Vbad	Vgood	Vgood	Bad

Appendices b-1: Rule application for overall sustainability assessment (cont.)

Ordinal	IF (ECONsus)	AND (SOCsus)	AND (ECOLsus)	THEN (Osus)
106	Bad	Vbad	Vgood	Bad
107	Bad	Bad	Vgood	Bad
108	Bad	Satisfactory	Vgood	Satisfactory
109	Bad	Good	Vgood	Satisfactory
110	Bad	Vgood	Vgood	Satisfactory
111	Satisfactory	Vbad	Vgood	Bad
112	Satisfactory	Bad	Vgood	Bad
113	Satisfactory	Satisfactory	Vgood	Satisfactory
114	Satisfactory	Good	Vgood	Good
115	Satisfactory	Vgood	Vgood	Good
116	Good	Vbad	Vgood	Bad
117	Good	Bad	Vgood	Satisfactory
118	Good	Satisfactory	Vgood	Good
119	Good	Good	Vgood	Good
120	Good	Vgood	Vgood	Vgood
121	Vgood	Vbad	Vgood	Bad
122	Vgood	Bad	Vgood	Satisfactory
123	Vgood	Satisfactory	Vgood	Good
124	Vgood	Good	Vgood	Vgood
125	Vgood	Vgood	Vgood	Vgood

Source: Synthesizing from stakeholder workshop, 2010

Appendices b-2: Rule application for economic sustainability assessment

Ordinal	IF (FR)	AND (IYT)	AND (EMC)	ECONsus
1	Low	Low	Low	Vbad
2	Low	Low	Medium	Bad
3	Low	Low	High	Bad
4	Low	Medium	Low	Bad
5	Low	Medium	Medium	Satisfactory
6	Low	Medium	High	Satisfactory
7	Low	High	Low	Bad
8	Low	High	Medium	Satisfactory
9	Low	High	High	Good
10	Medium	Low	Low	Bad
11	Medium	Low	Medium	Satisfactory
12	Medium	Low	High	Satisfactory
13	Medium	Medium	Low	Bad
14	Medium	Medium	Medium	Satisfactory
15	Medium	Medium	High	Good
16	Medium	High	Low	Satisfactory
17	Medium	High	Medium	Good
18	Medium	High	High	Good
19	High	Low	Low	Bad
20	High	Low	Medium	Satisfactory
21	High	Low	High	Satisfactory
22	High	Medium	Low	Satisfactory
23	High	Medium	Medium	Satisfactory
24	High	Medium	High	Good
25	High	High	Low	Satisfactory
26	High	High	Medium	Good
27	High	High	High	Vgood

Source: Synthesizing from stakeholder workshop, 2010

Appendices b-3: Rule application for social sustainability assessment

Ordinal	IF (ISS)	AND (EPL)	AND (AC)	AND (AAE)	THEN (SOCsus)
1	Low	Low	Low	Low	Vbad
2	Low	Low	Low	Medium	Vbad
3	Low	Low	Low	High	Vbad
4	Low	Low	Medium	Low	VBad
5	Low	Low	Medium	Medium	Bad
6	Low	Low	Medium	High	Bad
7	Low	Low	High	Low	VBad
8	Low	Low	High	Medium	Bad
9	Low	Low	High	High	Satisfactory
10	Low	Medium	Low	Low	VBad
11	Low	Medium	Low	Medium	Bad
12	Low	Medium	Low	High	Bad
13	Low	Medium	Medium	Low	Bad
14	Low	Medium	Medium	Medium	Satisfactory
15	Low	Medium	Medium	High	Satisfactory
16	Low	Medium	High	Low	Bad
17	Low	Medium	High	Medium	Satisfactory
18	Low	Medium	High	High	Satisfactory
19	Low	High	Low	Low	Bad
20	Low	High	Low	Medium	Bad
21	Low	High	Low	High	Bad
22	Low	High	Medium	Low	Bad
23	Low	High	Medium	Medium	Satisfactory
24	Low	High	Medium	High	Satisfactory
25	Low	High	High	Low	Bad
26	Low	High	High	Medium	Satisfactory
27	Low	High	High	High	Satisfactory
28	Medium	Low	Low	Low	Vbad
29	Medium	Low	Low	Medium	Bad
30	Medium	Low	Low	High	Bad
31	Medium	Low	Medium	Low	Bad
32	Medium	Low	Medium	Medium	Bad
33	Medium	Low	Medium	High	Satisfactory
34	Medium	Low	High	Low	Bad

Appendices b-3: Rule application for social sustainability assessment (cont.)

Ordinal	IF (ISS)	AND (EPL)	AND (AC)	AND (AAE)	THEN (SOCsus)
35	Medium	Low	High	Medium	Satisfactory
36	Medium	Low	High	High	Satisfactory
37	Medium	Medium	Low	Low	Bad
38	Medium	Medium	Low	Medium	Bad
39	Medium	Medium	Low	High	Satisfactory
40	Medium	Medium	Medium	Low	Bad
41	Medium	Medium	Medium	Medium	Satisfactory
42	Medium	Medium	Medium	High	Good
43	Medium	Medium	High	Low	Satisfactory
44	Medium	Medium	High	Medium	Good
45	Medium	Medium	High	High	Good
46	Medium	High	Low	Low	Bad
47	Medium	High	Low	Medium	Bad
48	Medium	High	Low	High	Satisfactory
49	Medium	High	Medium	Low	Bad
50	Medium	High	Medium	Medium	Good
51	Medium	High	Medium	High	Good
52	Medium	High	High	Low	Satisfactory
53	Medium	High	High	Medium	Good
54	Medium	High	High	High	Vgood
55	High	Low	Low	Low	Vbad
56	High	Low	Low	Medium	Bad
57	High	Low	Low	High	Bad
58	High	Low	Medium	Low	Bad
59	High	Low	Medium	Medium	Bad
60	High	Low	Medium	High	Satisfactory
61	High	Low	High	Low	Bad
62	High	Low	High	Medium	Bad
63	High	Low	High	High	Satisfactory
64	High	Medium	Low	Low	Bad
65	High	Medium	Low	Medium	Bad
66	High	Medium	Low	High	Satisfactory
67	High	Medium	Medium	Low	Bad
68	High	Medium	Medium	Medium	Satisfactory

Appendices b-3: Rule application for social sustainability assessment (cont.)

Ordinal	IF (ISS)	AND (EPL)	AND (AC)	AND (AAE)	THEN (SOCsus)
69	High	Medium	Medium	High	Good
70	High	Medium	High	Low	Satisfactory
71	High	Medium	High	Medium	Good
72	High	Medium	High	High	Good
73	High	High	Low	Low	Bad
74	High	High	Low	Medium	Bad
75	High	High	Low	High	Satisfactory
76	High	High	Medium	Low	Bad
77	High	High	Medium	Medium	Good
78	High	High	Medium	High	Vgood
79	High	High	High	Low	Satisfactory
80	High	High	High	Medium	Vgood
81	High	High	High	High	Vgood

Source: Synthesizing from stakeholder workshop, 2010

Appendices b-4: Rule application for environmental sustainability assessment

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
1	Low	Low	Low	Low	Low	Vbad
2	Low	Low	Low	Low	Medium	Vbad
3	Low	Low	Low	Low	High	Vbad
4	Low	Low	Low	Medium	Low	VBad
5	Low	Low	Low	Medium	Medium	VBad
6	Low	Low	Low	Medium	High	Bad
7	Low	Low	Low	High	Low	Bad
8	Low	Low	Low	High	Medium	Bad
9	Low	Low	Low	High	High	Bad
10	Low	Low	Medium	Low	Low	VBad
11	Low	Low	Medium	Low	Medium	Bad
12	Low	Low	Medium	Low	High	Bad
13	Low	Low	Medium	Medium	Low	Bad
14	Low	Low	Medium	Medium	Medium	Bad
15	Low	Low	Medium	Medium	High	Satisfactory
16	Low	Low	Medium	High	Low	Bad
17	Low	Low	Medium	High	Medium	Satisfactory
18	Low	Low	Medium	High	High	Satisfactory
19	Low	Low	High	Low	Low	Bad
20	Low	Low	High	Low	Medium	Bad
21	Low	Low	High	Low	High	Bad
22	Low	Low	High	Medium	Low	Bad
23	Low	Low	High	Medium	Medium	Satisfactory
24	Low	Low	High	Medium	High	Satisfactory
25	Low	Low	High	High	Low	Satisfactory
26	Low	Low	High	High	Medium	Satisfactory
27	Low	Low	High	High	High	Satisfactory
28	Low	Medium	Low	Low	Low	Vbad
29	Low	Medium	Low	Low	Medium	Bad
30	Low	Medium	Low	Low	High	Bad
31	Low	Medium	Low	Medium	Low	Bad
32	Low	Medium	Low	Medium	Medium	Bad
33	Low	Medium	Low	Medium	High	Bad
34	Low	Medium	Low	High	Low	Bad

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
35	Low	Medium	Low	High	Medium	Bad
36	Low	Medium	Low	High	High	Satisfactory
37	Low	Medium	Medium	Low	Low	Vbad
38	Low	Medium	Medium	Low	Medium	Vbad
39	Low	Medium	Medium	Low	High	Bad
40	Low	Medium	Medium	Medium	Low	Bad
41	Low	Medium	Medium	Medium	Medium	Bad
42	Low	Medium	Medium	Medium	High	Satisfactory
43	Low	Medium	Medium	High	Low	Bad
44	Low	Medium	Medium	High	Medium	Satisfactory
45	Low	Medium	Medium	High	High	Satisfactory
46	Low	Medium	High	Low	Low	Bad
47	Low	Medium	High	Low	Medium	Bad
48	Low	Medium	High	Low	High	Bad
49	Low	Medium	High	Medium	Low	Bad
50	Low	Medium	High	Medium	Medium	Satisfactory
51	Low	Medium	High	Medium	High	Satisfactory
52	Low	Medium	High	High	Low	Bad
53	Low	Medium	High	High	Medium	Satisfactory
54	Low	Medium	High	High	High	Satisfactory
55	Low	High	Low	Low	Low	Vbad
56	Low	High	Low	Low	Medium	Bad
57	Low	High	Low	Low	High	Bad
58	Low	High	Low	Medium	Low	Bad
59	Low	High	Low	Medium	Medium	Bad
60	Low	High	Low	Medium	High	Satisfactory
61	Low	High	Low	High	Low	Bad
62	Low	High	Low	High	Medium	Satisfactory
63	Low	High	Low	High	High	Satisfactory
64	Low	High	Medium	Low	Low	Bad
65	Low	High	Medium	Low	Medium	Bad
66	Low	High	Medium	Low	High	Bad
67	Low	High	Medium	Medium	Low	Bad
68	Low	High	Medium	Medium	Medium	Satisfactory

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
69	Low	High	Medium	Medium	High	Satisfactory
70	Low	High	Medium	High	Low	Bad
71	Low	High	Medium	High	Medium	Satisfactory
72	Low	High	Medium	High	High	Satisfactory
73	Low	High	High	Low	Low	Bad
74	Low	High	High	Low	Medium	Bad
75	Low	High	High	Low	High	Satisfactory
76	Low	High	High	Medium	Low	Bad
77	Low	High	High	Medium	Medium	Satisfactory
78	Low	High	High	Medium	High	Satisfactory
79	Low	High	High	High	Low	Bad
80	Low	High	High	High	Medium	Satisfactory
81	Low	High	High	High	High	Satisfactory
82	Medium	Low	Low	Low	Low	VBad
83	Medium	Low	Low	Low	Medium	Bad
84	Medium	Low	Low	Low	High	Bad
85	Medium	Low	Low	Medium	Low	Bad
86	Medium	Low	Low	Medium	Medium	Bad
87	Medium	Low	Low	Medium	High	Satisfactory
88	Medium	Low	Low	High	Low	Bad
89	Medium	Low	Low	High	Medium	Satisfactory
90	Medium	Low	Low	High	High	Satisfactory
91	Medium	Low	Medium	Low	Low	Bad
92	Medium	Low	Medium	Low	Medium	Bad
93	Medium	Low	Medium	Low	High	Bad
94	Medium	Low	Medium	Medium	Low	Bad
95	Medium	Low	Medium	Medium	Medium	Satisfactory
96	Medium	Low	Medium	Medium	High	Satisfactory
97	Medium	Low	Medium	High	Low	Bad
98	Medium	Low	Medium	High	Medium	Bad
99	Medium	Low	Medium	High	High	Satisfactory
100	Medium	Low	High	Low	Low	Bad
101	Medium	Low	High	Low	Medium	Bad
102	Medium	Low	High	Low	High	Bad

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
103	Medium	Low	High	Medium	Low	Bad
104	Medium	Low	High	Medium	Medium	Bad
105	Medium	Low	High	Medium	High	Satisfactory
106	Medium	Low	High	High	Low	Bad
107	Medium	Low	High	High	Medium	Satisfactory
108	Medium	Low	High	High	High	Satisfactory
109	Medium	Medium	Low	Low	Low	Bad
110	Medium	Medium	Low	Low	Medium	Bad
111	Medium	Medium	Low	Low	High	Bad
112	Medium	Medium	Low	Medium	Low	Bad
113	Medium	Medium	Low	Medium	Medium	Bad
114	Medium	Medium	Low	Medium	High	Satisfactory
115	Medium	Medium	Low	High	Low	Bad
116	Medium	Medium	Low	High	Medium	Satisfactory
117	Medium	Medium	Low	High	High	Satisfactory
118	Medium	Medium	Medium	Low	Low	Bad
119	Medium	Medium	Medium	Low	Medium	Bad
120	Medium	Medium	Medium	Low	High	Bad
121	Medium	Medium	Medium	Medium	Low	Bad
122	Medium	Medium	Medium	Medium	Medium	Satisfactory
123	Medium	Medium	Medium	Medium	High	Satisfactory
124	Medium	Medium	Medium	High	Low	Satisfactory
125	Medium	Medium	Medium	High	Medium	Satisfactory
126	Medium	Medium	Medium	High	High	Good
127	Medium	Medium	High	Low	Low	Bad
128	Medium	Medium	High	Low	Medium	Bad
129	Medium	Medium	High	Low	High	Satisfactory
130	Medium	Medium	High	Medium	Low	Bad
131	Medium	Medium	High	Medium	Medium	Satisfactory
132	Medium	Medium	High	Medium	High	Good
133	Medium	Medium	High	High	Low	Bad
134	Medium	Medium	High	High	Medium	Satisfactory
135	Medium	Medium	High	High	High	Good
136	Medium	High	Low	Low	Low	Bad

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
137	Medium	High	Low	Low	Medium	Bad
138	Medium	High	Low	Low	High	Bad
139	Medium	High	Low	Medium	Low	Bad
140	Medium	High	Low	Medium	Medium	Satisfactory
141	Medium	High	Low	Medium	High	Satisfactory
142	Medium	High	Low	High	Low	Bad
143	Medium	High	Low	High	Medium	Satisfactory
144	Medium	High	Low	High	High	Satisfactory
145	Medium	High	Medium	Low	Low	Bad
146	Medium	High	Medium	Low	Medium	Bad
147	Medium	High	Medium	Low	High	Satisfactory
148	Medium	High	Medium	Medium	Low	Bad
149	Medium	High	Medium	Medium	Medium	Satisfactory
150	Medium	High	Medium	Medium	High	Good
151	Medium	High	Medium	High	Low	Satisfactory
152	Medium	High	Medium	High	Medium	Good
153	Medium	High	Medium	High	High	Good
154	Medium	High	High	Low	Low	Bad
155	Medium	High	High	Low	Medium	Bad
156	Medium	High	High	Low	High	Satisfactory
157	Medium	High	High	Medium	Low	Bad
158	Medium	High	High	Medium	Medium	Satisfactory
159	Medium	High	High	Medium	High	Good
160	Medium	High	High	High	Low	Satisfactory
161	Medium	High	High	High	Medium	Good
162	Medium	High	High	High	High	Vgood
163	High	Low	Low	Low	Low	Bad
164	High	Low	Low	Low	Medium	Bad
165	High	Low	Low	Low	High	Bad
166	High	Low	Low	Medium	Low	Bad
167	High	Low	Low	Medium	Medium	Bad
168	High	Low	Low	Medium	High	Bad
169	High	Low	Low	High	Low	Bad
170	High	Low	Low	High	Medium	Satisfactory

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
171	High	Low	Low	High	High	Satisfactory
172	High	Low	Medium	Low	Low	Bad
173	High	Low	Medium	Low	Medium	Bad
174	High	Low	Medium	Low	High	Bad
175	High	Low	Medium	Medium	Low	Bad
176	High	Low	Medium	Medium	Medium	Satisfactory
177	High	Low	Medium	Medium	High	Satisfactory
178	High	Low	Medium	High	Low	Bad
179	High	Low	Medium	High	Medium	Satisfactory
180	High	Low	Medium	High	High	Satisfactory
181	High	Low	High	Low	Low	Bad
182	High	Low	High	Low	Medium	Bad
183	High	Low	High	Low	High	Bad
184	High	Low	High	Medium	Low	Bad
185	High	Low	High	Medium	Medium	Satisfactory
186	High	Low	High	Medium	High	Satisfactory
187	High	Low	High	High	Low	Bad
188	High	Low	High	High	Medium	Satisfactory
189	High	Low	High	High	High	Satisfactory
190	High	Medium	Low	Low	Low	Bad
191	High	Medium	Low	Low	Medium	Bad
192	High	Medium	Low	Low	High	Bad
193	High	Medium	Low	Medium	Low	Bad
194	High	Medium	Low	Medium	Medium	Satisfactory
195	High	Medium	Low	Medium	High	Satisfactory
196	High	Medium	Low	High	Low	Bad
197	High	Medium	Low	High	Medium	Satisfactory
198	High	Medium	Low	High	High	Satisfactory
199	High	Medium	Medium	Low	Low	Bad
200	High	Medium	Medium	Low	Medium	Bad
201	High	Medium	Medium	Low	High	Satisfactory
202	High	Medium	Medium	Medium	Low	Bad
203	High	Medium	Medium	Medium	Medium	Satisfactory
204	High	Medium	Medium	Medium	High	Good

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
205	High	Medium	Medium	High	Low	Satisfactory
206	High	Medium	Medium	High	Medium	Good
207	High	Medium	Medium	High	High	Good
208	High	Medium	High	Low	Low	Bad
209	High	Medium	High	Low	Medium	Bad
210	High	Medium	High	Low	High	Satisfactory
211	High	Medium	High	Medium	Low	Bad
212	High	Medium	High	Medium	Medium	Good
213	High	Medium	High	Medium	High	Good
214	High	Medium	High	High	Low	Satisfactory
215	High	Medium	High	High	Medium	Good
216	High	Medium	High	High	High	Vgood
217	High	High	Low	Low	Low	Bad
218	High	High	Low	Low	Medium	Bad
219	High	High	Low	Low	High	Bad
220	High	High	Low	Medium	Low	Bad
221	High	High	Low	Medium	Medium	Satisfactory
222	High	High	Low	Medium	High	Satisfactory
223	High	High	Low	High	Low	Satisfactory
224	High	High	Low	High	Medium	Satisfactory
225	High	High	Low	High	High	Satisfactory
226	High	High	Medium	Low	Low	Bad
227	High	High	Medium	Low	Medium	Bad
228	High	High	Medium	Low	High	Satisfactory
229	High	High	Medium	Medium	Low	Satisfactory
230	High	High	Medium	Medium	Medium	Satisfactory
231	High	High	Medium	Medium	High	Good
232	High	High	Medium	High	Low	Satisfactory
233	High	High	Medium	High	Medium	Good
234	High	High	Medium	High	High	Vgood
235	High	High	High	Low	Low	Bad
236	High	High	High	Low	Medium	Satisfactory
237	High	High	High	Low	High	Satisfactory
238	High	High	High	Medium	Low	Satisfactory

Appendices b-4: Rule application for environmental sustainability assessment (cont.)

Ordinal	IF (UCF)	AND (UOF)	AND (CLC)	AND (UCC)	AND (HH)	THEN (ECOLsus)
239	High	High	High	Medium	Medium	Good
240	High	High	High	Medium	High	Vgood
241	High	High	High	High	Low	Satisfactory
242	High	High	High	High	Medium	Vgood
243	High	High	High	High	High	Vgood

Source: Synthesizing from stakeholder workshop, 2010

DECLARATION

I declare that this dissertation is the result of my own work and that it has not been presented previously as a dissertation at this university or elsewhere. Furthermore, I declare that all sources have been duly acknowledged and that no other sources and application have been used besides those that are listed in the references.

Berlin, December 2012

Nguyen Tien Long